A software user guide for EMG Graphing and EMG Analysis

EMG Analysis

By Motion Lab Systems, Inc.

This manual was written by Motion Lab Systems using *ComponentOne Doc-To-Help.™*

Updated Tuesday, February 24, 2009

Intended Audience

This manual is written to provide a general description and usage guidelines for anyone using this application – it does not provide any clinical interpretation of the data that you may collect and analyze and no clinical interpretations should be assumed.

Operating Environment

This program runs on any 32-bit Microsoft operating system using an Intel compatible processor. This application should also run under current versions of WINE, an Open Source implementation of the Windows API on top of X and Unix that runs on Linux and FreeBSD operating systems, although full operation is not guaranteed under WINE.

It is assumed that the end-user is familiar with the operating system environment that they are using and no special reference is made to any specific operating system within this manual. Manuals for these operating systems are available from the appropriate sources – contact your supplier or system administrator if you need additional support for your operating system.

All Motion Lab Systems applications fully support the C3D file format. Detailed information on the C3D file format is available on the Internet at http://www.c3d.org - additional information on manufacturer specific C3D implementations may be obtained from your C3D application developer.

Year 2000 compliance

Motion Lab Systems, Inc. has reviewed and tested this application for Year 2000 (Y2K) compliance. The program will continue to function correctly on and beyond the year 2000.

Trademarks

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Contents

Introduction 1

EMG Analysis/Graphing 1
Installation Overview 4
Registration 7
Obtaining the current version 9

The EMG Signal 11

What is EMG? 11
Why is EMG measured and studied? 13
Relationship of EMG to physical parameters 14

Measurement of EMG Signals 17

How is EMG measured? 17
The Problem of Aliasing 20
Signal Levels 22
EMG Electrodes 24
Crosstalk 30

Making EMG Recordings 31

Preparation 31
Checking the EMG signal 32
Filtering the EMG signal 32
Analysis techniques 33
Interpretation 36
Application 36
EMG Data Collection 39

Signal Analysis methods 40

Analyzing EMG 40
Time domain analysis of the EMG signal 42
Frequency Analysis 45

Using your EMG program 49

The User Interface 49
The File menu 50
The Edit menu 60
View menu 72
The Scaling Menu 101
Analyze menu 109
Window menu 127

Help 129

Using the Help system 129

File Conversions 133

Discussion 133
Oxford Metrics ADC Files 134
BTS EMG Files 135
Dataq CODAS Files 137
Motion Analysis Corporation ANA Files 138
VAD Files 139

Installing the Software 141

Overview 141
Installation 141
Updating to the Current Version 148
Removing the Software 150

EMG Reporting Standards 151

Introduction 151

References 157

Sources used in this manual 157

Glossary of Terms 159

Index 163

Introduction

EMG Analysis/Graphing

Welcome to ***EMG Analysis*** and its companion program ***EMG Graphing***, both developed by Motion Lab Systems, Inc. The ***EMG Graphing*** program provides basic EMG displays and graphic output and is supplied free of charge with all Motion Lab Systems multi-channel EMG systems, while the ***EMG Analysis*** program is a full featured version, sold separately, that provides a wide range of analysis options.

The ***EMG Analysis*** software is a research quality EMG analysis program that implements powerful analysis methods using Fast Fourier Transform (FFT) techniques. This application, like the basic ***EMG Graphing*** program, fully supports all C3D formats as well as several older file formats (Vicon, BTS, Motion Analysis etc), and raw data from Dataq Data Acquisition systems for stand-alone functionality.

Site Licensed software is inexpensive, easy to administer, and use in all Research and Teaching environments.

Both the ***EMG analysis*** and the ***EMG Graphing*** software packages, like all Motion Lab Systems applications, are site licensed applications. The purchase of a software license allows multiple copies of the software to be used within a given environment, permitting its use on multiple computers, laptops etc., making it very easy to use in academic and research environments without any hardware access keys or restrictive licensing requirements.

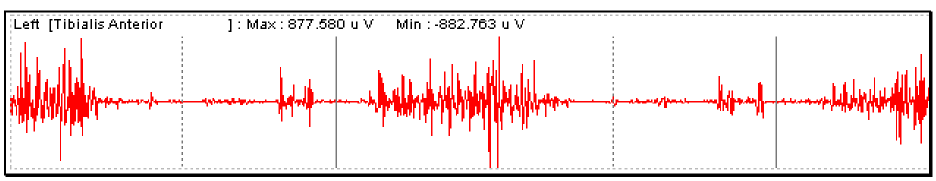


Figure 1 - The software applications open and display EMG data in any C3D file.

These are some of the most powerful, yet easy to use, software packages using FFT analysis that are available to both the clinician and researcher. Kinesiologist driven, and written directly to clinical specifications, this software makes full use of the graphical user interface to effortlessly deliver instant data viewing and full color reports using sophisticated Frequency Spectrum, Power Spectrum and Muscle Correlation techniques as well as simple trial base graphics that show the user the entire date collection as soon as the data file is opened.

Features

The ***EMG Analysis*** and ***EMG Graphing*** programs analyze EMG data recorded a number of different Motion Capture and Data Collection sources as well as any C3D file. The two applications share a large number of common baseline features with additional, advanced features available only in the ***EMG Analysis*** version.

These two programs are both exceptionally easy to use and provide the electromyographer with the ability to rapidly display and analyze raw EMG data that has been recorded using any of a number of data collection systems listed below:

- .ADC Files (Oxford Metrics/Vicon RSX and VMS systems.)
- .ANA Files (Motion Analysis Corporation.)
- .C3D Files (Biomechanics standard file specification.)
- .EMG Files (BTS TeleEMG systems.)
- .WDQ Files (Dataq CODAS data acquisition systems.)

Full information about the C3D format, including a manual, is available at http://www.c3d.org.

All of the "manufacturer specific" formats listed above are converted to the C3D format whenever ***EMG Analysis*** or ***EMG Graphing*** application saves a file that it has opened so that all the analog information is stored in a standard biomechanics format for access in the future. The C3D format is a public specification that supports the storage of 3D positional information (marker trajectories) as well as analog sample information.

If you have EMG data in a different format please contact Motion Lab Systems, Inc., to see if support for your format has been added recently.

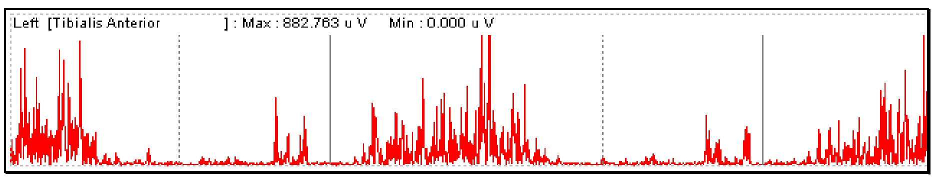


Figure 2 - Both Analysis and Graphing applications support rectified EMG displays.

The ***EMG Analysis*** and ***EMG Graphing*** programs both analyze pre-recorded EMG data, based on the assumption that an action is being performed that has a definite start and stop time - a cycle time in the gait world. The common application of this type of analysis is human gait, where the repetitive stride action of the muscles is analyzed although there are many other repetitive actions that can be treated in the same way. This cycle time may be defined by the use of mechanical contact switches (foot switches in gait measurements), by using data from force plates in conjunction with marker trajectories, or by entering the event times to define the period (or periods) of EMG activity that we want to analyze.

This manual provides detailed user instruction for both the ***EMG Graphing*** application and the ***EMG Analysis*** applications together with an introduction to the art of collecting EMG data and basic electromyograpical analysis. Both programs share a common set of functions and work in basically the same way. Functions that are specific to the ***EMG Analysis*** version of the software are noted in each instance throughout the manual.

The EMG Graphing Application

The ***EMG Graphing*** program is a basic version of the ***EMG Analysis*** program that supports the *graphing and display* of the EMG data while the later program provides a wide range of the more complex *analysis* functions. Both applications provide

identical support for the graphing, display and printing of the raw EMG data and use the same Graphical User Interface making it easy to upgrade from the basic ***EMG Graphing*** application to the more sophisticated ***EMG Analysis*** application at any time. Please contact Motion Lab Systems, Inc. if you are interested in purchasing a license for the ***EMG Analysis*** Software.

CAMARC GCD and DST files are ASCII files that conform to a published standard and can be easily accessed by other users.

In addition to displaying and printing the raw EMG data, the Motion Lab Systems ***EMG Analysis*** program provides a number of different analysis methods. The electromyographer can generate a wide variety of reports that can be displayed, printed, or written to CAMARC standard GCD and DST files, or industry standard C3D files for averaging, or further analysis and display.

Both ***EMG Analysis*** and ***EMG Graphing*** provide identical analysis methods for:

- Raw EMG cycle display
- Full Wave Rectified EMG cycle display

Both applications contain many common functions and display and treat trial data identically. Both applications include “normal” activity information and permit the user to create additional normal datasets, detect EMG activity based on event activity, and export data using the ASCII GCD file format. Both applications fully support the C3D file format.

EMG Analysis Application

The ***EMG Analysis*** application supports the following analysis functions in addition to the basic functions of the ***EMG Graphing*** software:

- Zero Crossing Detection
- Moving Average (user selected window)
- Linear Envelope (user selectable filter frequency)
- RMS Analysis
- Intensity Filtered Average
- Threshold Detection
- Integrate over Time
- Integrate and Reset
- EMG Power Spectrum (FFT)
- Amplitude Distribution (FFT)
- Co-contraction

In addition, the ***EMG Analysis*** application allows the user to save various EMG processing results to the C3D file as additional EMG data channels and can export individual EMG channels as audio data using the standard .wav format as well as replaying EMG data through a suitable audio system.

The ***EMG Analysis*** and ***EMG Graphing*** programs are 32-bit applications, written and tested to run on all 32-bit Microsoft operating systems. Both the ***EMG Analysis*** and the ***EMG Graphing*** programs are supplied with sample data and a full installation setup and removal program.

Anyone may run the programs in the evaluation mode, which limits them to only operating on the sample C3D data files supplied with the installation. This evaluation version can be converted to the fully functional version be purchasing a registration key from Motion Lab Systems.

The registered versions of both the ***EMG Graphing*** and the ***EMG Analysis*** applications include a full color manual and support of one year – software support contracts are also available, please contact Motion Lab Systems for details.

Installation Overview

A full description of the installation, update and removal of your program can be found at the end of this manual.

You can use the *Add/Remove Programs* option in Control Panel to install ***EMG Analysis*** or ***EMG Graphing*** from a CD-ROM or, if you download a copy from our web site (www.motion-labs.com), then just run the installation file – called emganalysis_install.exe which will install one of the three versions, depending on your answers to questions during the installation. This will install the desired application on your system together with some example EMG data files that you can use to demonstrate and explore the programs.

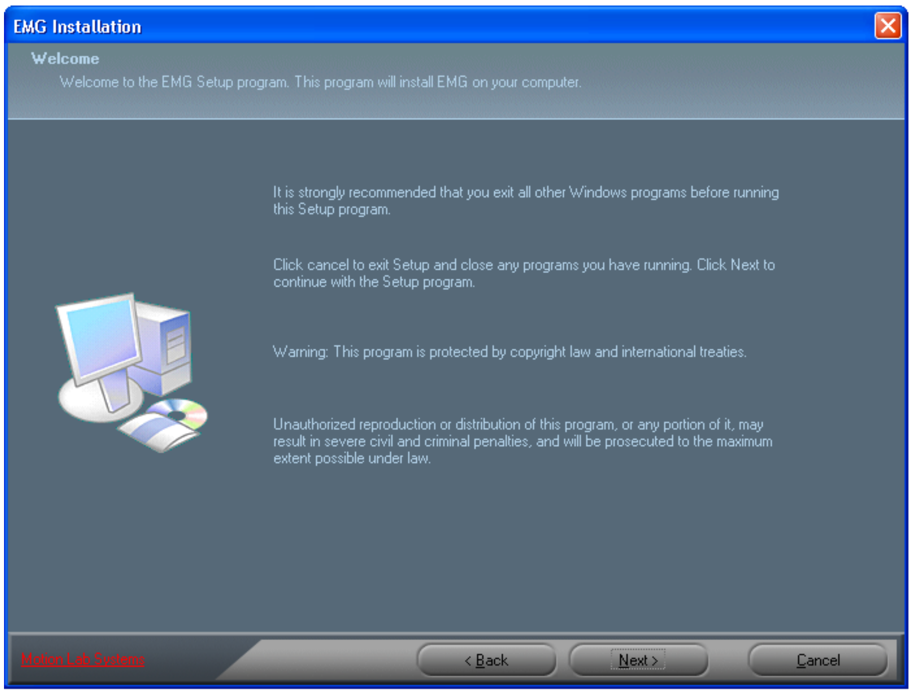


Figure 3 – All versions of EMG Analysis and EMG Graphing are installed from the same file.

During the installation you will be asked some question about the version of the software that you are installing – the first questions is, "Are you installing the EMG Graphing version?" – answer **YES** if you received the software when you purchased a Motion Lab Systems EMG system. If you answer **YES** at this point then the software will automatically install the ***EMG Graphing*** version.

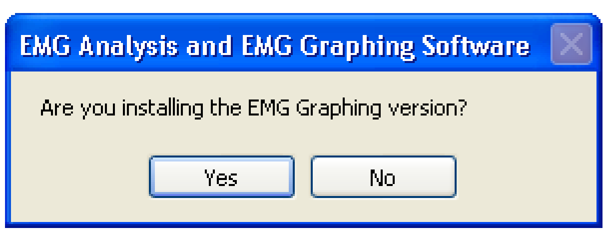


Figure 4 - Answer ***YES*** *if you are installing the EMG Graphing version*

If you answer **NO** then you will be asked if you are installing the evaluation version of the software. The evaluation version is a copy of the ***EMG Analysis*** software that

works with the supplied demonstration C3D files but will not open C3D files that are not included with installation. Answer **YES** if you want to install the evaluation version of the ***EMG Analysis*** software.

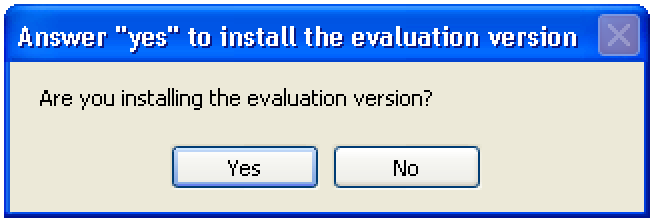


*Figure 5 - Answer **NO** if you are installing the full EMG Analysis version.*

If you answer **NO** to the question, "Are you installing the evaluation version?" then the installation program will assume that you are installing the full version of the ***EMG Analysis*** software and will prompt you to enter a license number – if you have not purchased a license then you can run in evaluation mode by entering *0000-0000-0000-0000* as the serial number so that you can try out the product before you purchase a copy. If you have purchased a copy then enter your license number together with your User Name and Organization details exactly as supplied by Motion Lab Systems.

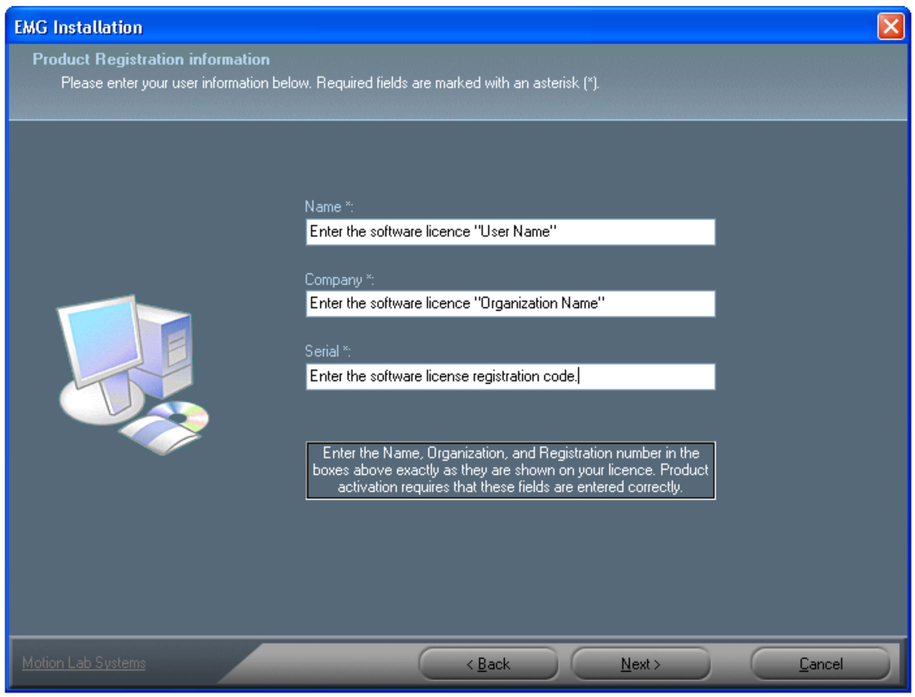


Figure 6 - The EMG Analysis version requires that you enter your registration information.

If you accept the default options during installation, then you will have created a short-cut in the Motion Lab Systems menu group called ***EMG Analysis*** or ***EMG Graphing***, together with a desktop short-cut.

Motion Lab Systems may release new versions of these programs in order to fix bugs or add new features.

The software application will display the name of the registered user whenever the program is started. This information is also displayed in the About dialog box accessed from the help drop-down menu. This can be opened by choosing the About command (Help menu) or by clicking on the help icon in the Toolbar. This dialog box will also show you the version number of the program. Check the Motion Lab Systems web site for the current version of the ***EMG Analysis*** or ***EMG Graphing*** application.

Application Versions

The software will operate in one of three different modes, depending on the installation and registration of the software.

The Evaluation Version

Please contact Motion Lab Systems if you have a specific C3D file that you would like watermarked so that it can be used to evaluate either program.

Both ***EMG Analysis*** and ***EMG Graphing*** can run in an evaluation mode so that you can try out the products before you purchase a copy. In the evaluation mode, the applications will only open the watermarked C3D Files supplied with the software. The programs will be fully functional with these files and you can save the results of any analysis operation back to these files. All attempts to open EMG data files from other sources will produce an error message.

If you decide to purchase either the ***EMG Analysis*** or ***EMG Graphing*** software after evaluation, then you may contact Motion Lab Systems for a registration key and printed manual.

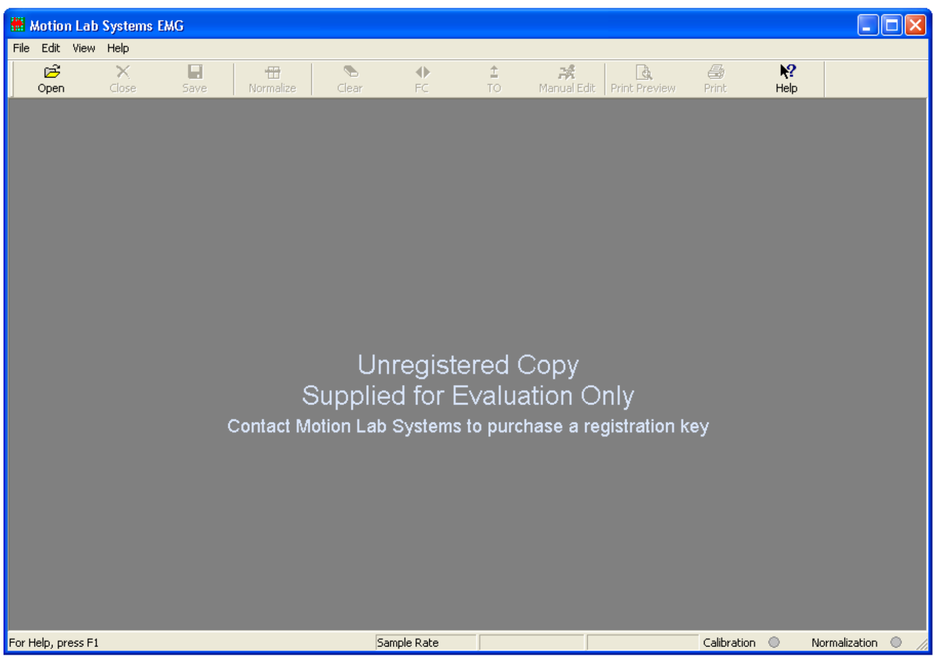


Figure 7 – The startup screen displayed by the unregistered version of the software.

If you are purchasing a copy of either the ***EMG Graphing*** or ***EMG Analysis*** packages then you may request a specific *User Name* and *Organization* be used to generate your registration information. If these are suitable (they fully describe the user and location of the program license) then a registration code will be created and your specific *User Name* and *Organization* will be displayed when the application starts up and at the bottom of all printed output produced by the programs.

This option is not available if you have installed the version of the ***EMG Graphing*** software that is included with each MA-300 EMG system. These versions use a predefined registration configuration.

The EMG Graphing Version

EMG Graphing is licensed for use at free of charge by anyone who uses a Motion Lab Systems EMG system.

This version differs from the full ***EMG Analysis*** version in that it only displays and graphs raw gait cycle data – the more complex analysis functions are not supported in the graphing version. Both the ***EMG Graphing*** and ***EMG Analysis*** packages support the full display and printing of multiple cycles of EMG activity from a single trial of data. Both packages fully support the display of gait, or other cyclic activity, events as well as the display of a range of normal activity bars on both trial and processed data.

The ***EMG Graphing*** application is ideal for electromyographers who require printed reports of basic EMG activity for trials involving multiple cycles of data or single events but do not want to perform complex data analysis.

The EMG Analysis Version

The ***EMG Analysis*** version supports all the features of the ***EMG Graphing*** version and adds support for a wide variety of analysis functions for gait cycle activities including, multi-level EMG level detection, window averaged and filtered envelope displays, frequency and power spectrum displays and muscle activity correlation.

In addition to generating and printing the same cycle related reports as the ***EMG Graphing*** application, ***EMG Analysis*** supports the creation of standard CARMAC DST/GCD data files as well as providing the ability to process and store the results of EMG processing within the C3D file for access by other software packages.

Registration

If you have installed the evaluation version, or you did not enter the registration information correctly during installation, then the application will run in the evaluation mode. In the evaluation mode that program will function as a licensed copy of the EMG Analysis application with the watermarked C3D files that are installed with the application; however the evaluation version will not open C3D files from other sources.

If this happens than you can enter the correct registration information using the ***Register…*** option from the help menu. This will convert the application to a fully functional registered application once the correct information is entered.

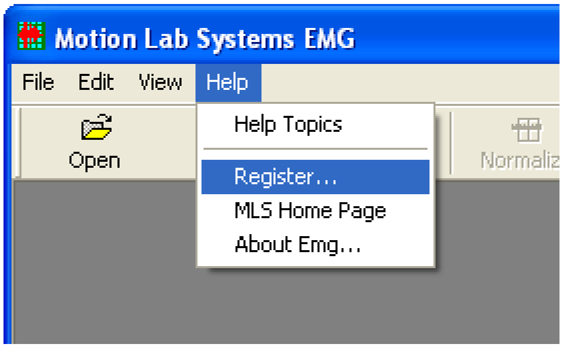


Figure 8 - Select the Register option from the help menu.

The ***Register…*** option will display the current registration information, including the registration number if the product is unregistered, otherwise the words *Licensed Copy* will be displayed if the registration process has been completed.

If anything other than *Licensed Copy* appears in the registration number box then you will need to enter the correct information, or edit and correct the current information – note that the **User Name** and **User Organization** must be entered *exactly* as shown on the registration information provided by Motion Lab Systems. This information, together with other factors such as the program version number etc., is used to generate a registration check when the program is used.

The **User Name** and **User Organization** are assigned by Motion Lab Systems when the EMG Analysis version of the applications is purchased. Both the **User Name** and **User Organization** will be displayed at lower left side of all printed analysis pages produced by the ***EMG Analysis*** software while the ***EMG Graphing*** software will simply display the words *Registered MA-300 User*.

All Motion Lab Systems software purchased after Jan 1, 2008 will include checksum information. Checksum information for older software is available on request.

The registration process will display a four digit checksum on the right side of each of the three registration fields – this number is calculated using an algorithm that produces a unique number for each data entry. As a result, the checksum number will match the checksum number that is provided with the registration documentation if the data has been entered correctly. As a result it can be used to verify that the registration entries exactly match the information that is provided by Motion Lab Systems when the software license is purchased.

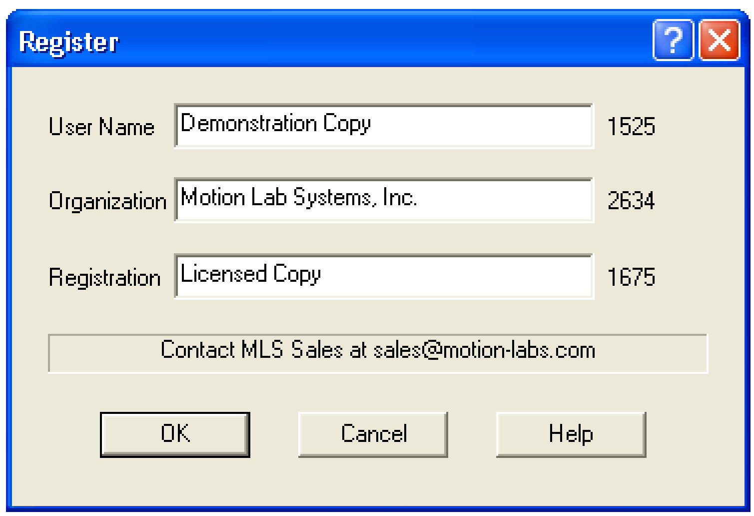


Figure 9- The registration number is hidden once the application is registered.

Almost all software registration problems are due to entering User Name or User Organization information that does not match the details provided on your registration certificate from Motion Lab Systems. Normally a quick check of the supplied checksum numbers will enable you to quickly figure out which of the three fields has been entered incorrectly because the checksum supplied by Motion Lab Systems will not match the checksum displayed in the registration screen. If you have an error then simply re-enter the data field in error so that the checksum matches the number supplied with your registration.

If the information that you enter is incorrect then the checksum will not match the checksum provided with the registration information and the product will only run as a demonstration version – please contact Motion Lab Systems to obtain the correct information.

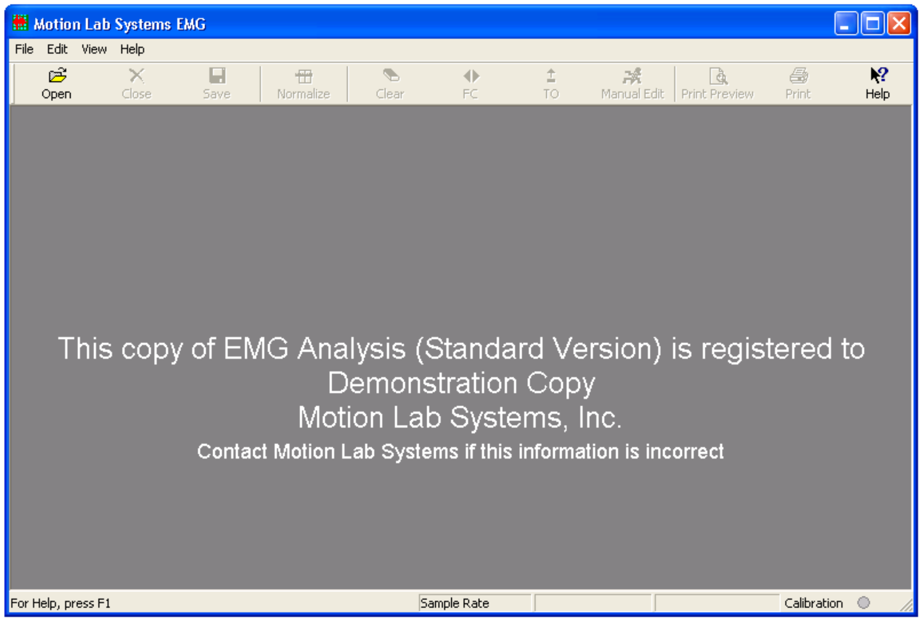


Figure 10 – The program will display the register 'user' and 'organization' when it starts.

Once the registration process has been completed successfully the registration information will become a permanent part of the background displayed when the application first starts. The program is properly licensed if the displayed information correctly identifies the current user.

Obtaining the current version

One year's software support is included with both the EMG Analysis and EMG Graphing versions of the software.

As a registered user of the ***EMG Analysis*** or ***EMG Graphing*** programs, you are automatically entitled to maintenance updates, bug fixes and feature upgrades for the point version of the software that you are using. For example, if you have purchased version 3 of the software, you will receive all applicable bug fixes and feature upgrades for all versions of the software from 3.000 to 3.999 – upgrading to version 4 of the software will require that you have a software support contract.

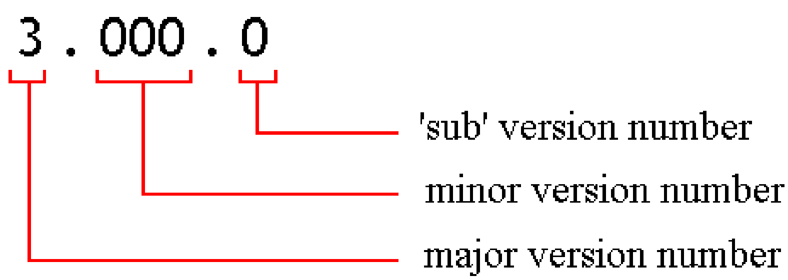


Figure 11 - The Motion Lab Systems version number system.

We issues new versions of the software whenever a bug is discovered and fixed, or whenever a new feature is added to the software. Software updates that change some portion of the application or modify the way that the application works will change the three digit 'minor' version numbers while updates that do not affect the core software application will change only the 'sub' version number.

Significant changes to the software – usually modifying the application involving rewriting a large portion of the code or appearance of the software will change the 'major' version number. Changes to related files, and particularly documentation changes, will result in a new 'sub' version number – for example a version change from 3.045 to 3.045.1 indicates a minor change that does not include changes to the application code. A version change of 3.045 to 3.046 indicates a change in the application code while a version change of 3.045 to 4.000 will be a major upgrade involving significant changes in the way that the application works.

Motion Lab Systems software support contacts are available at reasonable prices and one contract will cover all software packages that you are licensed to install. If you do not have a software support contact then you will have to purchase the new version if you wish to upgrade.

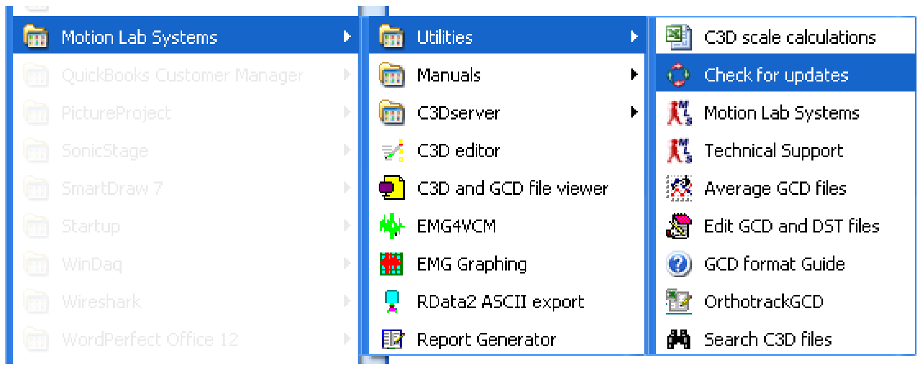


Figure 12- You can check for updates and download them automatically via the internet.

You can obtain the current software updates by downloading a new copy of the software from the http://www.motion-labs.com web site or by simply running the ***Check for updates*** option in the Motion Lab Systems *Utilities* group if you have direct access to the internet. The ***Check for updates*** utility contacts our FTP site and checks to see if a software update has been released for any of our programs.

Check for updates is a third-party utility that is installed when the main EMG application is installed – this utility reads the current software version levels from our FTP site and will offer you the opportunity to download the current version of each supported application that is available. No information about your system or configuration is passed to Motion Lab Systems – the utility simply reads the current software release levels from Motion Lab Systems and then tells you if there is an update available. You can then decide if you wish to download and install any available updates.

The EMG Signal

What is EMG?

While this manual aims to provide an overview of electromyography with an emphasis on its use in movement analysis, it expects that the general reader will approach it with a good idea of what the general process of EMG Analysis entails. The following chapters can not pretend to give the reader all the knowledge needed to becoming a proficient electromyographer but rather they try to provide an overview of the processes involved and, when augmented with other readings and materials, the average reader should be able to utilize either of the ***EMG Analysis*** and ***EMG Graphing*** software applications as tools in their research.

Electromyography is the study of muscle function based on the examination and analysis of the electrical signals that emanate from the muscles.

The electromyogram (EMG) is an electrical manifestation of the contracting muscle – this can be either a voluntary or involuntary muscle contraction. The EMG signal is a complicated signal which is affected by the anatomical and physiological properties of muscles, the control scheme of the peripheral nervous system, as well as the instrumentation used for detection of the EMG signal and the process used to record the EMG signals. Variations in any of these processes can affect the character of the signal and the analysis and conclusions drawn from the data.

The basic functional unit of the muscle contraction is a motor unit, which is comprised of a single alpha motor neuron and all the fibers it enervates. This muscle fiber contracts when the action potentials of the motor nerve which supplies it reaches a depolarization threshold. The depolarization generates an electromagnetic field which is measured as a very small voltage that we call EMG.

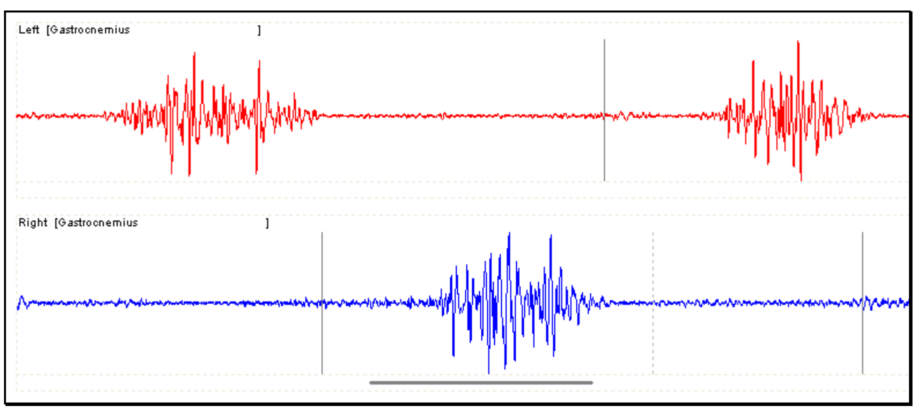


Figure 13 - An EMG signal showing clean muscle activation (recorded with an MA-300).

As you might expect from this brief description, the essential nature of the EMG signal is complex and many people have devoted their lives to its study. We will devote the next few paragraphs to a very brief summary, working on the assumption that the reader can find many excellent books on the subject if they are interested in learning more about this fascinating field of biology.

While EMG can have many different types of voluntary or involuntary causes, the initial source of the signal is that an action potential propagates down a motor neuron to activate the branches of the motor neuron. These in turn activate the muscle fibers of a motor unit. When the post-synaptic membrane of a muscle fiber is depolarized, the depolarization propagates in both directions along the fiber. The membrane depolarization, along with a movement of ions, generates an electromagnetic field in the vicinity of the muscle fibers. The time excursion of this voltage is called the muscle action potential.

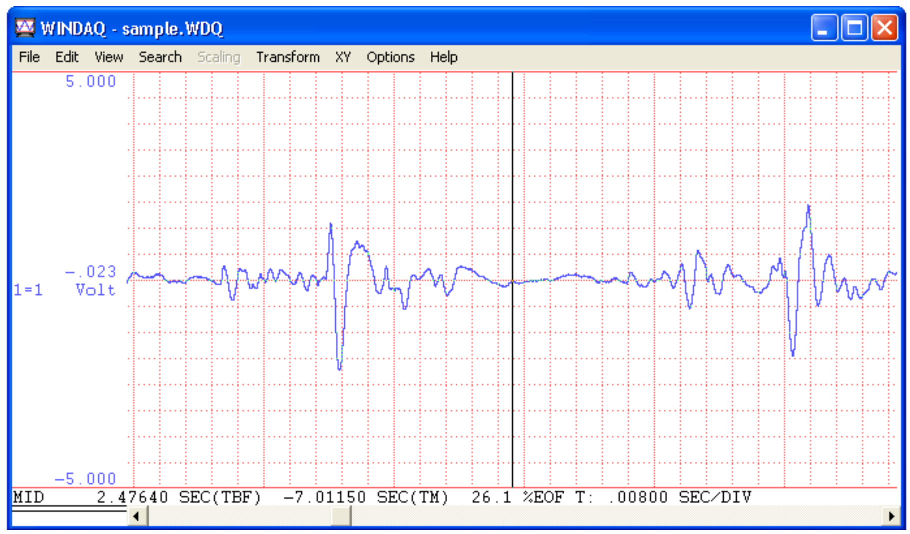


Figure 14 - The EMG signal is the algebraic summation of individual MUAPs.

The motor unit action potential is the spatial and temporal summation of the individual muscle action potentials for all the fibers of a single motor unit. Therefore, the EMG signal is the algebraic summation of the motor unit action potentials within the pick-up area of the electrode being used. Unless the electrode is very small, the pick-up area of an electrode will almost always include more than one motor unit because muscle fibers of different motor units are intermingled throughout the entire muscle. Any portion of the muscle may contain fibers belonging to as many as 20-50 motor units.

As a result, the typical EMG represents the activation of multiple motor units. The collected data is an asynchronous series of action potentials that vary in amplitude and duration due to the differences in the distance of the electrode from the muscle fibers and the length of the axon extending to the muscle fiber. The EMG is a composite of the two mechanisms used to increase muscle force, recruitment of additional motor units and a more rapid firing of the same motor units.

A single motor unit can have 2-3,000 muscle fibers. Muscles controlling fine movements have smaller numbers of muscle fibers per motor units (usually less than ten fibers per motor unit) than muscles controlling large gross movements (which have 100-1,000 fibers per motor unit). There is a hierarchy arrangement during a muscle contraction as motor units with fewer muscle fibers are typically recruited first, followed by the motor units with larger muscle fibers. The number of motor

units per muscle is variable throughout the body and may vary from one subject to another.

Why is EMG measured and studied?

As far as we're concerned for the purposes of this manual, EMG contains two types of important information, timing of muscle activity and its relative intensity. Other information is also present (e.g. frequency spectrum and acoustic information) but most clinical diagnostic reports are based on the muscle activity and intensity components of the EMG signal. This information can be used within a wide variety of fields of study:

- Numerous neuromuscular disorders may present aberrant EMG signals while performing functional tasks like posture and locomotion. This may be any combination of inappropriate muscle activation or errors in muscle activation intensity.
- Biomedical engineers often use EMG signals to derive volitional control of an artificial limb or brace through the interpretation of the EMG signal.
- Biomechanists and other scientists can study the balance mechanism by which humans maintain postural stability in the presence of perturbations.
- Gait analysis laboratories study the precise control of the musculo-skeletal system during ambulation or other complex human movements.
- Doctors often evaluate the temporal sequence of the recorded activity to address questions of CNS control. Often called "nerve conduction", this is a rapidly growing field of study that is quite separate from the multi-channel, muscle activation studies that this manual addresses.
- Researchers study multi-channel EMG data together with biomechanical parameters, such as muscle force to investigate the relationships between different muscle contractions.
- EMG alone can be used to differentiate normal gait from pathologic gait by comparing recorded EMG timing to the normal EMG timings for a given subject population for any gait activity.

For the purposes of this manual, there are two main types of electromyography:

Clinical EMG – sometimes called "diagnostic EMG" or "Nerve Conduction EMG" is typically done by physiatrists and neurologists. This is the study of the characteristics of the motor unit action potential for duration and amplitude. These studies are typically done to help diagnostic neuromuscular pathology. They also evaluate the spontaneous discharges of relaxed muscles and are able to isolate single motor unit activity. Generally, these types of studies focus on a single muscle or group of muscles.

Kinesiological EMG – this is the type most often found in the literature regarding movement analysis. This type of EMG examines the relationship of muscular function to movement of the body segments and evaluates timing of muscle activity with regard to the movements. Additionally, many studies attempt to examine the strength and force production of the muscles themselves. Kinesiological EMG almost invariably looks at the actions, and interactions, of several muscles simultaneously.

Both the ***EMG Analysis*** and ***EMG Graphing*** software applications focus almost exclusively on providing information from the viewpoint of Kinesiological EMG

studies that involve multiple muscle contractions during physical activity. As a result, the rest of this manual will discuss EMG from a Kinesiological point of view.

Relationship of EMG to physical parameters

There is a direct relationship between EMG and many biomechanical variables. With respect to isometric contractions, there is a positive relationship between the increase of tension within the muscle and the amplitude of the EMG signal recorded. During any contraction there is a lag time as the EMG amplitude does not directly match the build-up of isometric tension. Because of this, it is difficult to reliably estimate the force production from the recorded EMG signal, as there is questionable validity of the relationship of force to amplitude when many muscles are crossing the same joint, or when muscles cross multiple joints.

When looking at muscle activity, with regards to concentric and eccentric contractions, it is common to find that eccentric contractions produce less muscle activity than concentric contraction when working against equal force. As the muscle fatigues, one sees a decreased tension despite constant or even larger amplitude of the muscle activity. There is a loss of the high-frequency component of the signal as it fatigues, which can be seen by a decrease in the median frequency of the muscle signal. Thus, during movement, there tends to be a relationship with EMG and velocity of the movement.

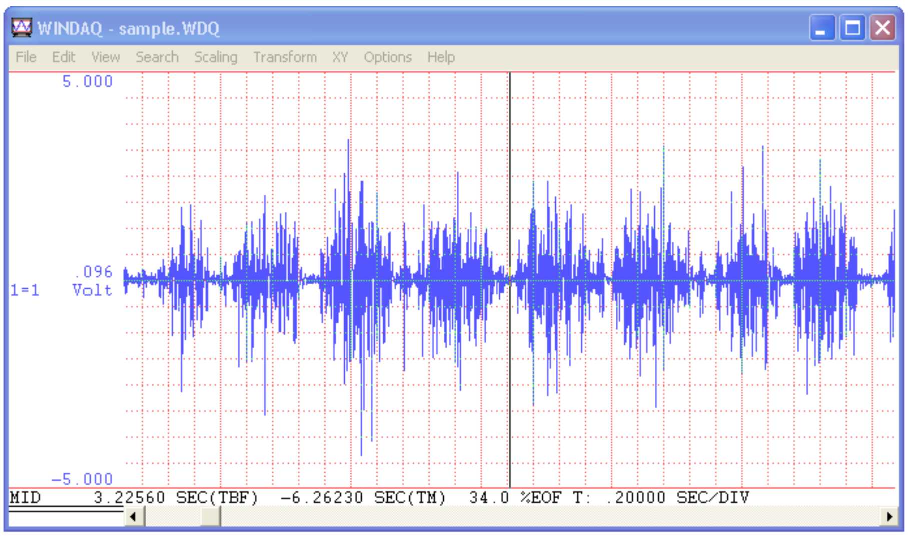


Figure 15 - There is a correlation between muscle contractions and physical actions.

There is an inverse relationship of strength production with concentric contractions and the speed of movement, while there is a positive relationship of strength production with eccentric contractions and the speed of movement. One can handle more of a load with eccentric contractions at higher speed. For example: If a weight was very large and you lowered it to the ground in a fast, but controlled manner, you handled a large weight at a high speed via eccentric contractions. You would not be able to raise the weight (concentric contraction) at the same speed you were able to lower it. The forces produced by the fibers are not necessarily any greater, but you were able to handle a larger amount of weight and the EMG activity of the muscles handling that weight would be smaller. Thus, we have an inverse relationship for concentric contractions and positive relationship for eccentric contractions with respect to speed of movement.

Joint motion

Kinematic plots of joint angular motion can be compared to the EMG plots recorded at the same time to see if one set of data can explain the other. In many cases the addition of kinetic plots to the EMG serves to clarify the picture of the subject's activity. Muscle function in gait is one of control, with onset of eccentric activity for protection against motion occurring in the opposite direction.

Force

The amplitude of EMG signals derived during gait may be interpreted as a measure of relative muscle tension. The EMG processed through a linear envelope has been widely used to compare the EMG-tension relationship, especially if the tension is changing with time. For constant tension experiments, it has been reported that the average value of the rectified EMG is a measure of tension. This can be derived from a long time constant linear envelope circuit. Both linear and non-linear relationships between EMG amplitude and tension have been reported.

There is considerable research into using EMG recordings to estimate muscle forces although; it has to be admitted, often with mixed success. Force estimations are usually calculated based on either the rectified signal or after appropriate low-pass processing of the rectified EMG signal.

Basmajian & De Luca define MUAP as the detected waveform consisting of the spatiotemporal summation of individual muscle fiber action potentials originating from muscle fibers in the vicinity of a given pair of electrodes.

The estimated force signal obtained by passing a rectified EMG signal through a second order Butterworth filter has been found to lag behind the raw EMG data and is believed to be due to the fact that the twitch corresponding to each Motor Unit Action Potential (MUAP) reaches its peak 40-100 ms afterward. Thus as each motor unit is recruited, the resulting summation of twitch forces will also have a similar delay behind the EMG. The timing relationship of the MUAP is affected by a number of factors including tissue between the muscle and electrode, electrode type, electrode placement.

Velocity

There is agreement with the fact that increased velocity elongates the period of muscle activity by leading the activity that starts earlier or lasts longer. It has been found that the EMG amplitude increases with increasing walking speed and that the EMG activity is minimized with subjects walking at their comfortable speed. It has been suggested that without a speed constraint, subjects selected a walking velocity associated with a minimum of muscle activity.

Muscle Fatigue

Fatigue in muscles is one of the more interesting in physiology – it is an effect that is common to all muscles. While it is believed to be chemical in nature, the long held theory that muscle fatigue is due to the release of lactic acid has been thoroughly discredited. Current research into the flow of calcium between muscle cells appears to show some promise of resolving the mysteries of the muscle exhaustion.

From an electromyographical point of view, fatigue has been found to not only reduce the muscle force, but also to alter the shape of the motor action potentials. A correlation has shown that there is an increase in the average duration of the recruited MUAP and fatigue levels. The EMG spectrum is also shown to have shifted to reflect these changes. Simply put, it has been found that higher frequency components of the EMG spectrum decreased with fatigue.

Measurement of EMG Signals

How is EMG measured?

The EMG signal is obtained from the subject by either measuring non-invasively with surface electrodes, or invasively with wire or needle electrodes. The measured signal is then amplified, conditioned and recorded to yield a format that is most convenient for answering the clinical or scientific question of concern. The measurement and recording of a complex analog signal such as EMG is a complex subject as the signals of interest are invariably very small (in the order of 0.00001 to 0.005 of a Volt). In addition, the signals are usually found in combination with very large spurious signals from motion artifact, as well as induced voltages from nearby AC power lines, florescent lights, cell phones and other electrical equipment such as computers, monitors etc. – all of which are potent sources of interference. As a result, both a quality EMG system and a versatile analog signal recording system are essential if you are planning anything more than the most casual of analysis functions.

Recording Systems

Three types of recording device are commonly used - these are strip chart recorders, multi-channel analog tape recorders, and computer-controlled data recorders. In each case, the frequency response of the recording device must be at least equal that of that of the EMG signal being recorded. For surface EMG signals, this is generally considered to be 10Hz to 500Hz, while needle (fine-wire) recordings directly from the muscle may produce signals in the range of 2Hz to 1,000Hz.

Direct, on-line recording of the EMG signal directly into the computer is the preferable system today, especially when the EMG signal is analyzed as part of a gait or motion study. Advances in processor speed, memory size and disk access times all have contributed to the popularity of this method. There are a large number of data collection systems available for personal computer systems and most clinical gait analysis systems include or offer analog data collection options with sample rates that are high enough to accurately represent the EMG signal. Both the Motion Lab Systems ***EMG Analysis*** and ***EMG Graphing*** programs are compatible with the files produced by many common motion capture systems.

Motion Lab Systems offers a wide range of cabled EMG systems that offer superior performance at competitive costs.

The transmission of EMG signals from the subject to the recording system can be either by cable or by telemetry. Cabled EMG systems tend to offer higher signal bandwidths and better reliability than telemetry systems but require that the subject be attached in some way to the recording system. Telemetry EMG systems usually offer the subject a greater freedom of movement than cabled systems but are almost always heavier, have lower signal bandwidths, are more prone to signal artifacts, telemetric interference and usually considerably more expensive.

The quality of the recorded EMG signals is principally controlled by two factors. These are the *sampling rate* of the recording system and the amount of *artifact*, or non-EMG components in the recorded signal.

Analog Sampling Constraints

The Nyquist–Shannon sampling theorem is a fundamental result in the field of information theory and signal processing. The theorem is commonly called the *Shannon sampling theorem*, and is also known as *Nyquist Theorem*, or the *Cardinal Theorem of Interpolation Theory*. It is often referred to as simply the *sampling theorem* and defines the sampling conditions that are required in order to perfectly reconstruct the original signal from a series of discrete values.

If the sampling conditions are not satisfied, then frequencies will overlap; that is, frequencies above half the sampling rate will be reconstructed as frequencies below half the sampling rate. The resulting distortion is called aliasing and the reconstructed signal is said to be an alias of the original signal, in the sense that it has the same set of sample values yet does not replicate the original analog signal.

For a sinusoidal signal of exactly half the sampling frequency, the sampled signal will, in general, alias to another sinusoid of the same frequency, but with a different phase and amplitude.

There are only two things that can be done to prevent signal aliasing – either increase the sampling rate, to above twice that of the frequencies that are aliasing, or introduce an anti-aliasing filter to restrict the bandwidth of the signal to satisfy the condition for proper sampling.

Sampling Rate

The sampling rate is the frequency at which the EMG data is sampled or measured. Thus a sampling rate of 1000 Hz means that the EMG signal is measured 1000 times every second. This means that the maximum rate at which the EMG signal can change and still be accurately reproduced, is 500 Hz – this limits the high end bandwidth of the EMG signal. In practice, it is recommended that the EMG signal be sampled at least four to five times faster than the highest frequency component that is expected to be present in the signal if any signal analysis is to be performed. At a minimum, the EMG signal must be sampled at least twice as fast as the highest frequency component within the signal.

Thus, while an EMG signal that is recorded using surface electrodes could be sampled as slow as 1000 Hz, the optimum sample rate is 2000-2500Hz. Fine wire (or indwelling) EMG signals would need to be sampled at a minimum of 2000Hz and optimally at rates as high as 4000-5000Hz.

It is beyond the scope of this manual to cover all of the issues involving the finer points of analog data sampling techniques. However, in any digital sampling system it is absolutely essential that the analog signal to be recorded is low-pass filtered prior to the recording to remove any signal components that change faster than the system can measure. In the examples above, (surface EMG and indwelling EMG

recordings) the signal would have to be filtered at 500Hz and 1000Hz to eliminate the possibility of artifact.

If your EMG system does not include a low-pass filter then it will be necessary to determine the frequency response of the system and sample the EMG data at least four times that value to avoid aliasing artifact problems. This is because an EMG system claiming a bandwidth of up to 500Hz is usually quoting the 3dB point – the frequency at which the amplitude of the input signal is 3dB lower than the amplitude of a mid-band signal (250Hz in this case).

Thus the unfiltered EMG system in this example can produce low-level signals above the quoted 500Hz bandwidth. These "out-of-band' signals, if present at the input of the digital sampling system, can produce significant amounts of aliasing artifact and appear as "ghost" or "alias" signals in the DC to 500Hz range. Alias signals that are recorded as a result of sampling errors in this way can not be filtered or removed from the data by any subsequent processing.

Artifact

To have an ideal, valid recording, the incoming EMG data, presented to the recording system, should contain no artifact components. Since the vast majority of EMG studies are performed on moving, live subjects this is often virtually impossible to achieve. Mechanical artifacts are common and occur when the EMG signal cables move as the subject is in motion, as well as from any movement of the EMG sensor electrode on the skin surface. Cable artifact can generate low frequency signals as the EMG signal wires shift during the subjects' motion. This is a particular problem with passive surface electrodes if the cables to the electrode are long and are often not secured to prevent undue motion. For this reason Motion Lab Systems recommends the use of miniature preamplifiers at the skin surface or close to the signals source in the case of fine wire needles. The low-impedance signals from the preamplifiers are immune to motion-induced artifact.

Artifacts can be generated by movement occurring at the electrode-skin interface if the electrodes are not attached to the subject correctly and the electrode or preamplifier is free to move against the surface of the skin. These artifacts are usually of a low frequency - generally below 20Hz but can have amplitudes that are very much larger than the EMG signal that you are attempting to measure.

Other muscles in the body can generate EMG – and if these muscles are close to the testing site that you are interested in then cross-talk, valid but unwanted EMG signals, can be recorded. There is some evidence that intra muscle cross-talk can be reduced by the use of a special double differential preamplifier electrode but close attention to electrode placement is the best remedy to reduce cross-talk.

In addition, EMG recordings anywhere close to the subjects heart may detect the subjects pulse (the QRS complex has signal components above 50Hz) as a regular beat underlying the EMG signal that is being collected for investigation.

Another artifact that can be a major problem is AC line interference (50 or 60Hz depending on where you live), which is often a symptom of poor electrode application or a faulty EMG preamplifier. Modern EMG preamplifiers with high Common Mode Rejection Ratios (CMRR) of greater than 100dB have largely eliminated this as a problem. Generally the presence of AC line artifact is good indicator that there is an electrode interface problem – a loose, or detached electrode.

Under some circumstances high frequency artifact can be generated if there is a high RF signal level in the recording lab from a local radio transmitter or the subject is using a cell phone. Other potential RF sources include microwave ovens, television, video conferencing and CB radios although in general, a well designed modern EMG system will be impervious to all forms of RF interference.

In addition, aliasing artifact can be generated by the EMG recording system if there are components of the incoming signal that are higher in frequency than twice the recording system sample rate. This can occur because of faulty EMG system design that permits RF or other out-of-band signals to enter the EMG inputs, or because of analog data collection systems that respond to out-of-band signals.

The Problem of Aliasing

Aliasing is a potential sampling problem in any signal acquisition system. It can cause erroneous results and occurs whenever the incoming analog signal contains frequency components that are at, or higher than, half the analog signal sampling rate. If the incoming EMG signal is not filtered to remove all frequencies greater than this limit, then the higher frequencies will show up as alias signals – false, lower frequency, components in the recorded EMG signal that cannot be distinguished from valid sampled data. The alias signals are remnants of the imperfectly recorded higher frequency signals that are “folded back” by the sampling process to create false low frequency signals below half the sampling rate. This new, and completely false signal, is completely indistinguishable from a signal in the source EMG signal.

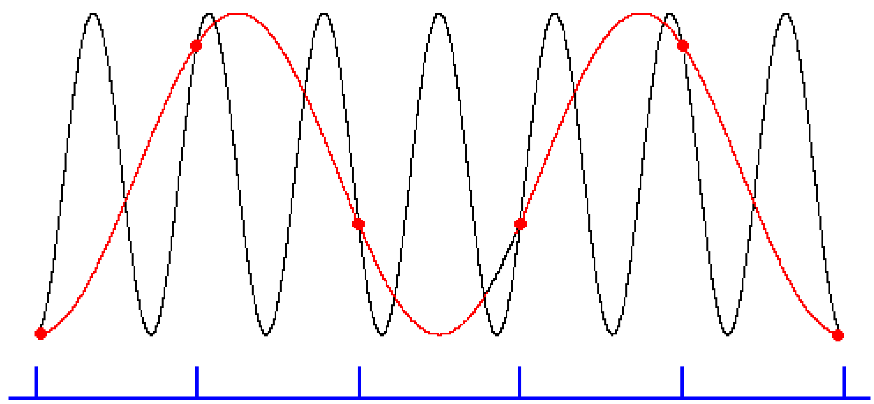


Figure 16 - The signal (black) is sampled too slowly (blue) creating the false (red) artifact.

For example, with a sampling rate of 1,000 Hz, any EMG components in the signal that are above 500 Hz will be aliased to appear as EMG signals in the range of DC to 500 Hz (the actual range of EMG signals that the sampling system is capable of recording) thus leaving errors in different locations throughout your data each time you use an A/D converter.

Let’s consider what happens when the sampling rate is too low – to illustrate the problem with some real numbers we’ll use a test signal consisting of two sine waves within the normal EMG bandwidth. One signal is a 35Hz sine wave, the other signal is a 180Hz sine wave.

If the ADC sampling process uses a sampling frequency of 400Hz (which is greater than 2*180Hz) and the reconstruction process has a bandwidth limit of 200Hz. As a result, we will obtain two frequency components when we examine the data at 35Hz and 180Hz.

But what if the original signal’s highest frequency is not the expected 180Hz but in fact 213Hz?

With the same 400Hz sampling frequency we find that the data now appears to show a reconstructed signal consisting of a pair of 35Hz and 187Hz (400-213) sine waves because the 400Hz sample rate is too low to accurately record the 213Hz signal. The

213Hz signal has been transformed into at 187Hz signal as a result of aliasing. This example is a very simplistic model but it illustrates how the aliasing phenomenon associated with erroneous sampling processes can corrupt the EMG data.

Figure 17- A stand-alone 32channel USB ADC sub-system that supports oversampling.

While it may appear that the aliasing problem can be eliminated by sampling the EMG signal at a very high rate, such over-sampling of data requires faster A/D conversion - often at rates that are not supported by many analog recording systems. Higher sampling rates also produce larger files that contain more data to process and depending on the situation may not guarantee that aliasing will not be a problem.

The only practical way of avoiding the possibility of aliasing errors is to filter the bandwidth of the analog EMG signal so that the signal presented to the A/D sampling system does not contain any frequency components above one-half of the A/D sample rate. This is easily done with a good quality low-pass Butterworth or Bessel anti-alias filter on each A/D input channel prior to the A/D converter. Low-pass filtering must always be done before the signal is sampled as there is no way to remove the aliasing errors from the original signal once it has been digitized.

As dictated by the Nyquist theory, the EMG signal needs to sampled by the A/D converter at a rate that is, at a minimum, twice as fast as the highest frequency component within the EMG signal. This rule applies to any sampling system and the filter point is often referred to as the Nyquist frequency and all frequency components above this point must be removed before sampling.

A perfect low-pass filter would pass all EMG signal components with frequencies from DC to the filter cutoff frequency while completely suppressing all frequencies above the filter point. Unfortunately, it is not possible to build a perfect filter with an exact cut off point and all analog filters pass some frequencies above the cut off point. This is called the roll-off or attenuation slope where small amounts of signals are still present, although at a much lower level than the original. These attenuation slopes are normally greater than 40-50 dB/octave and attenuate the frequency components in the original signal that are greater than the cut-off point by 80 to 100 dB.

It is important to realize that high-frequency components in any signal presented to an A/D system can result from a number of different sources that are unrelated to the EMG signal from the muscle. High frequency signals above the Nyquist point may come from the inherent noise of the EMG system itself, and from noise or interference, broadcasting stations, and mechanical vibrations. High-frequency components also are inherent in any sharp transitions of the measured signal such as may occur when equipment subject to any unexpected vibration (e.g. dropped etc). Low-pass filters generally can eliminate alias errors from the recorded EMG signal as long as the filters precede the A/D converter. A low-pass filter serves as an

important element of any data acquisition system in which the accuracy of the acquired data is essential.

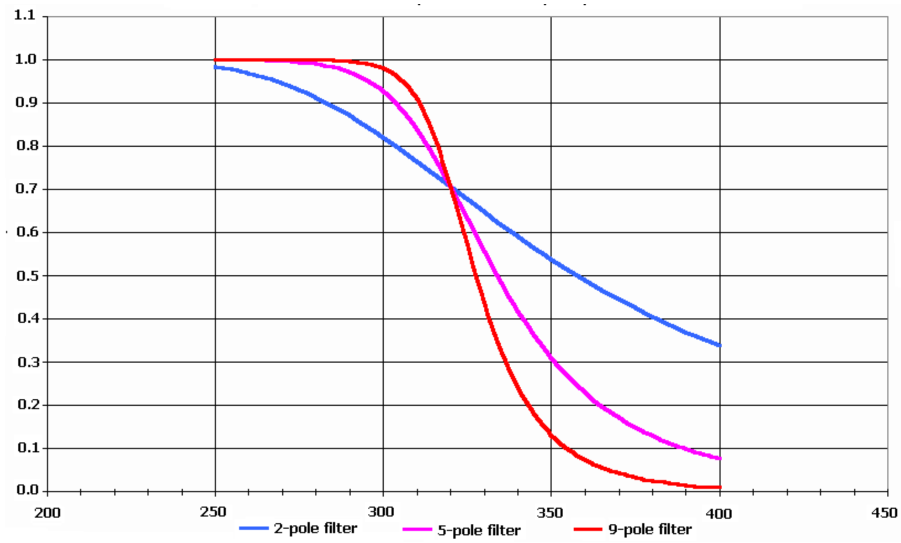


Figure 18- The relative amplitude frequency response for a 320Hz Butterworth filter

Aliasing artifact can be eliminated as a potential problem by paying close attention to the actual bandwidth of the signal being recorded and by filtering the signal before sampling. When selecting a filter frequency and sampling rate remember that many filters do not have very sharp cut-off points. As a result, a filter set to give a 500Hz cutoff may still pass measurable frequencies up to 600-700Hz depending on the quality of the filter.

Signal Levels

Most modern EMG recording systems are Analog to Digital Converter (ADC) based system. These systems work by repeatedly measuring and recording the EMG signal level – usually at very high speed across multiple channels.

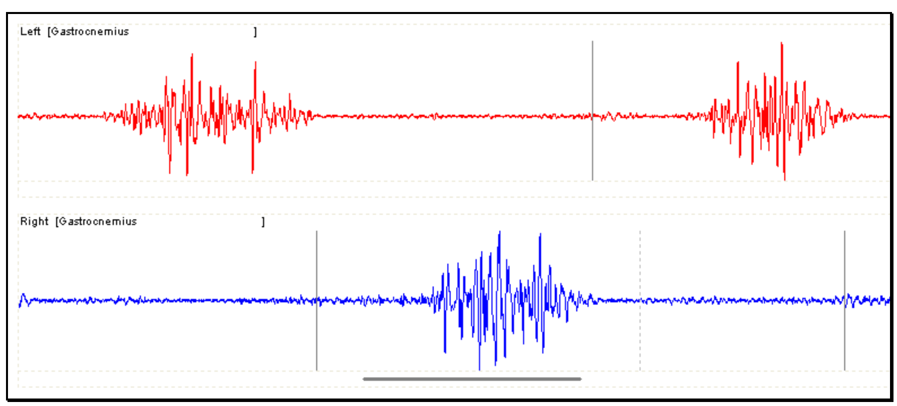


Figure 19 - EMG recorded at the correct level is large enough for analysis but not clipped.

Most ADC recording systems store the sampled EMG data as series of numbers with a limited range, usually either 2^{12} or 2^{16} unique values (i.e. 4096 or 65536 unique values) which represent the recorded analog signal, both positive and negative values, usually over the range of ±5 volts. As a result, it is important that all of the EMG signals presented to the ADC recording device use the entire recording range

and should look very much like the illustration in Figure 19. This signal allows the signal peaks to be clearly distinguished (they are not clipped or squared off at the top and bottom of the signal) and shows a moderately quiet baseline signal in between the bursts of EMG activity.

Selecting the correct ADC recording range is very important - if your ADC data collection is set-up for ±10 volts and your EMG system is producing EMG signals that are in the ±1volt range (after amplification) then you will lose resolution – the ability to distinguish small changes in the recorded signal. This is shown in Figure 20 where it is very difficult to determine the precise onset and cessation of the EMG activity because the recorded EMG signals are too low.

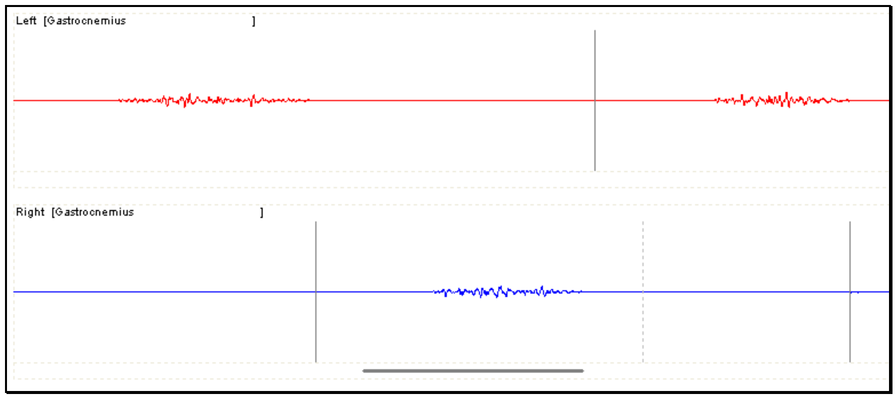


Figure 20 - EMG recorded at too low a level is difficult to observe or analyze.

However, having the gain set too low is not as bad as the results of setting the gain too high. If your ADC collection system is set-up with an input signal range of ±5 volts and your EMG system is producing (after amplification) signals in the ±10 volt range then you will find that the EMG signal is clipped at ±5 and appears to have a lot of baseline noise. This is illustrated in Figure 21 where all of the EMG bursts can be seen to stop at a single point at the top and bottom of the display – this distortion of the recorded signal is called “clipping”. The clipping of the EMG waveform means that you have no way of measuring any change in the EMG signal above the ±5 level and the apparent increase in baseline noise can lead to interpretation errors in some cases. In addition, the frequency content of the clipped signal is altered, invalidating any frequency or power analysis of the recorded signal.

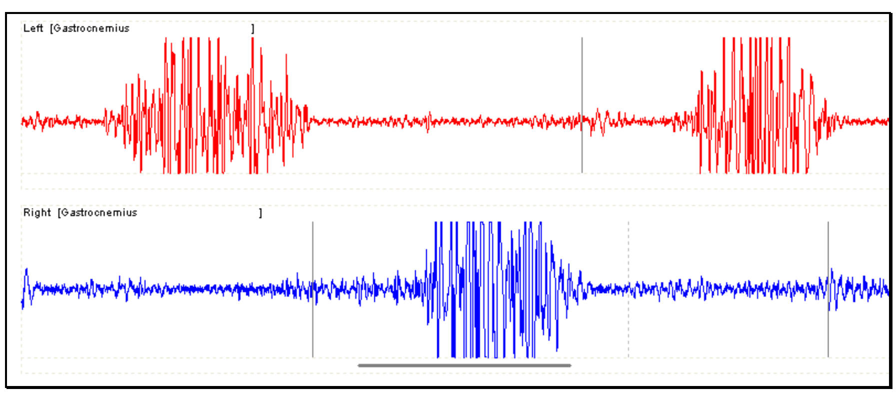


Figure 21 - EMG recorded at too high a level is distorted and provides limited information.

Therefore, it is very important that the software and hardware arrangement used to record the EMG signal allows for optimization of the collected voltage range within the measured range. Generally, this requires that the EMG system used provide a

wide range of gain settings to allow the optimum EMG level to be presented to the ADC recording system.

If in doubt – always select a lower signal gain than a higher one as low-level EMG signals can be amplified by the ***EMG Analysis*** and ***EMG Graphing*** programs to produce accurate results. Setting the EMG gain too high and causing the EMG signals to clip and be distorted, renders most analysis techniques useless as the clipping changes the frequency spectrum of the recorded EMG signal.

EMG Electrodes

The EMG signal is measured either non-invasively with surface electrodes, or invasively, with wire or needle electrodes. Since typical EMG signal levels are in the region of 400 µV to 3 mV (depending on many factors), the measured EMG signal is almost always pre-amplified, amplified and conditioned to yield a format that is most convenient for answering the clinical or scientific question of concern.

The detection electrode for kinesiological EMG is typically bipolar, and the EMG signal is amplified differentially. The waveform of the observed action potential will depend on the orientation of the detection electrode contacts with respect to the active fibers.

EMG can be recorded from the skin surface or by placing an electrode directly within the subject's muscle – this is usually referred to as a fine-wire recording. Surface EMG is generally recorded with either passive or active electrodes placed on the intact skin surface over the subjects muscle, while fine-wire recordings use a wire electrode that is inserted into the muscle by a trained (and, in most cases, licensed) professional. Each electrode type has specific advantages and disadvantages.

With regards to recording the EMG signal, the amplitude of the motor unit action potential depends on many factors which include the diameter of the muscle fiber, the distance between active muscle fiber and the detection site (adipose tissue thickness), and filtering properties of the electrodes themselves. The objective is to obtain a signal free of noise (i.e., movement artifact, line frequency interference, etc.). Therefore, the electrode type and amplifier characteristics play a crucial role in obtaining a noise-free signal. For kinesiological EMG there are two main types of electrodes: surface and fine wire.

Surface Electrodes

Surface electrodes used in EMG recordings can either be "active" or "passive" electrodes. In the passive electrode type, the electrode consists of a simple silver/silver-chloride detection surface that senses a current on the skin through the skin-electrode interface. This type of electrode is normally used when the electromyographer requires precise placement or if older EMG equipment in use. Active electrodes place a preamplifier either within the electrode or very close to the EMG data collection site. The advantages of surface electrodes are that there is minimal pain with application, they are more reproducible, they are easy to apply, and they are very good for movement applications. The disadvantages of surface electrodes are that they have a large pick-up area and therefore, have more potential for cross talk from adjacent muscles.

Surface electrodes are easy to apply and use, and they provide a good indication of muscle activity, with minimum discomfort to the subject. However the ability of surface electrodes to record the activity of small muscles, or muscles located deep within the body such as the Tibialis Posterior is very limited. In spite of this

limitation, surface EMG recording are the most common type of kinesiological EMG recordings.

Passive Electrodes

Passive electrodes generally need to be used with an electrode gel to ensure a good skin contact. The principal advantages of this type of electrode are that they are reusable, and that they are small enough to be mounted close together in areas that would be very difficult to measure with any other method. This allows the trained electromyographer to position the EMG pickup areas with great precision. However, they are often very messy to use and have generally been replaced by disposable electrodes when a passive electrode would normally be required unless the target muscle is very small.

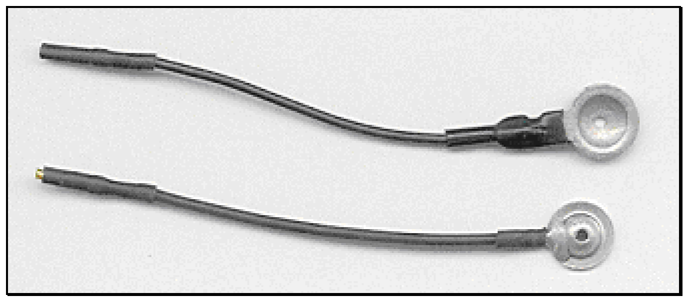


Figure 22 – Typical Silver/Silver Chloride (Ag/AgCl) Electrodes

Disposable gel electrodes, suitable for surface EMG recordings, can be purchased from Motion Lab Systems, Inc.

Disposable electrodes are widely used for EKG monitoring and are commonly available in a bewildering variety of shapes and sizes. The majority of these commercial electrodes are designed for long term (24 hours) adult EKG monitoring and as a result are less than ideal for most EMG applications. The ideal EMG electrode should be small and lightweight – specialized EKG electrodes designed for pediatric intensive care units usually work quite well. The principal advantages of disposable gel electrodes are that they are very easy to use, they allow the electromyographer complete control over the placement of the EMG measuring location and that they can be disposed after a single use.

When using passive electrodes it is very important that the signal cables used to transfer the EMG signal from the electrode on the skin surface to the EMG equipments are very carefully secured to reduce the possibility of motion artifact appearing in the EMG signal. Motion artifact appears as very low frequency shifts in the baseline of the EMG signal and can overwhelm the EMG signal in extreme instances.

Passive electrodes rely on cables to transfer the very low level EMG signal some distance (anything from 2 to 20 feet) to the amplification equipment. Since the EMG signal is collected at the skin surface, it has a relatively high impedance (typically in the order of 50,000 to 200,000 ohms). While is it desirable to lower this skin resistance figure as much as possible, this can require the use of conducting gels and extensive skin preparation – both of which can contribute additional problems to the EMG recording. Research papers often quote lower figures for skin resistance (in the orders of 5,000 to 10,000 ohms) but these are not generally attainable in the kinesiological EMG setting without considerable discomfort to the subject due to the extensive skin debrading necessary to produce these numbers.

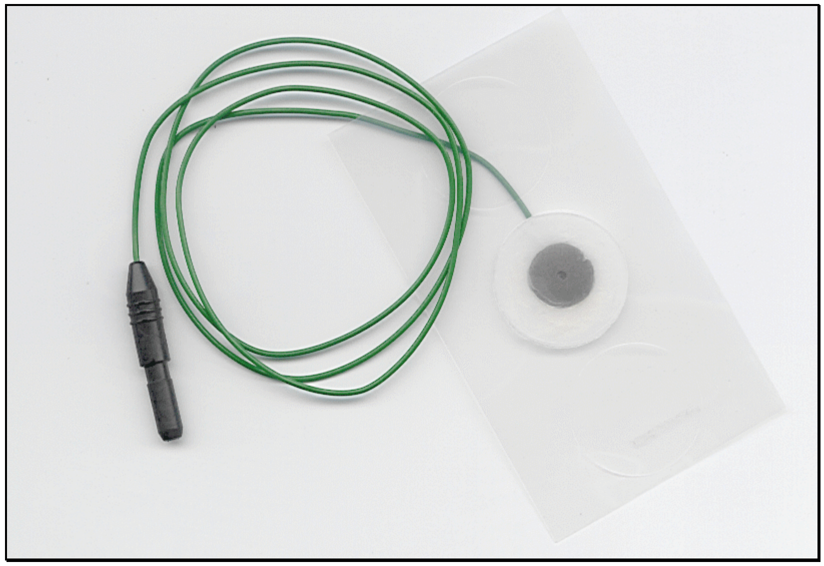


Figure 23 – A disposable electrode with safety 'touchproof' connector

Thus signal transferred from the passive electrode, through the cable, is both low level and highly sensitive to external interference from a wide variety of external sources while it is transferred through the cabling. As a result, the available signal to noise ratio decreases and any movement artifacts picked up by the cable are amplified along with the actual signal once amplification occurs.

Active Electrodes

An active electrode contains an electronic circuit that will amplify the EMG signal close to the site of the signal pickup. These devices are commonly referred to as pre-amplifiers because the EMG signal is amplified prior to being transferred to the main instrumentation amplifier. The EMG pre-amplifier within the active electrode boosts the level of the electrical signal from the skin surface (typically in the range of 0.00001 to 0.001 volts) to levels closer to 0.01 to 1.0 volts, depending on the degree of amplification (gain) provided. In addition to amplifying the EMG signal, the active electrode also provided two other important functions by rejecting any common mode interference from AC line interference, and by providing a low impedance signal from the active electrode to the rest of the EMG data collection system. This greatly improves the signal to noise ratio of the EMG signal and, in addition, eliminates any possibility of picking up motion artifact in the cable from the pre-amplifier to the rest of the EMG system.

The measure of the ability of the EMG preamplifier to eliminate the common mode signal is termed the common mode rejection ratio – usually abbreviated to CMRR. The higher the common mode rejection ratio, the better the cancellation of any signals that are common to both amplifier inputs – these are almost invariably noise signals. A value of 90dB or higher is desirable although it should be noted that comparing the CMRR values of devices from different manufacturers is risky as the precise number can be heavily influenced by the measurement conditions – a device reporting a CMRR value of 100dB may not perform significantly better than a device with a 90dB ratings unless both devices are tested under the same conditions.

Active surface electrodes are available in two basic types - those that require a separate "indifferent" or "ground reference" electrode and those that include a third reference pad in the electrode package.

The failure to use a ground reference electrode is the major cause of AC power line interference in the recorded EMG signal.

Always follow the electrode manufacturer's recommendations for maximum signal quality – if a separate ground reference electrode is recommended then it must be used. Generally, a ground (or indifferent) electrode is a single gel or pad electrode that is attached to some convenient point on the subject to provide a neutral reference to the EMG recording system.

There are several preamplifier characteristics that need to be considered when recording either surface or fine-wire EMG signals. The first of which is the signal to noise ratio of the preamplifier. This can be quoted in two different ways, as the ratio of the wanted signal to the unwanted signal, or as a simple noise level, usually with respect to the input signal. In either case, it is a measure of the quality of the amplified signal – high signal to noise ratios and low noise figures both indicate a high quality preamplifier in most cases. Miniature EMG preamplifiers at the site of, or including, the EMG electrode are almost invariably the best at providing a very large signal to noise ratio.

The gain of the preamplifier is also important. Higher gains provide a greater amplification of the EMG signal and any signal artifact – for this reason, it is a good idea to use a relatively low gain preamplifier at the muscle site to avoid overloading subsequent amplification stages if large artifact signals occur. Too large a gain at the muscle site may cause the EMG signal to disappear in the presence of low frequency artifact as the larger artifact signals, correspondingly amplified to a high level, and may saturate any additional amplifiers, causing the EMG signal to be distorted or lost.

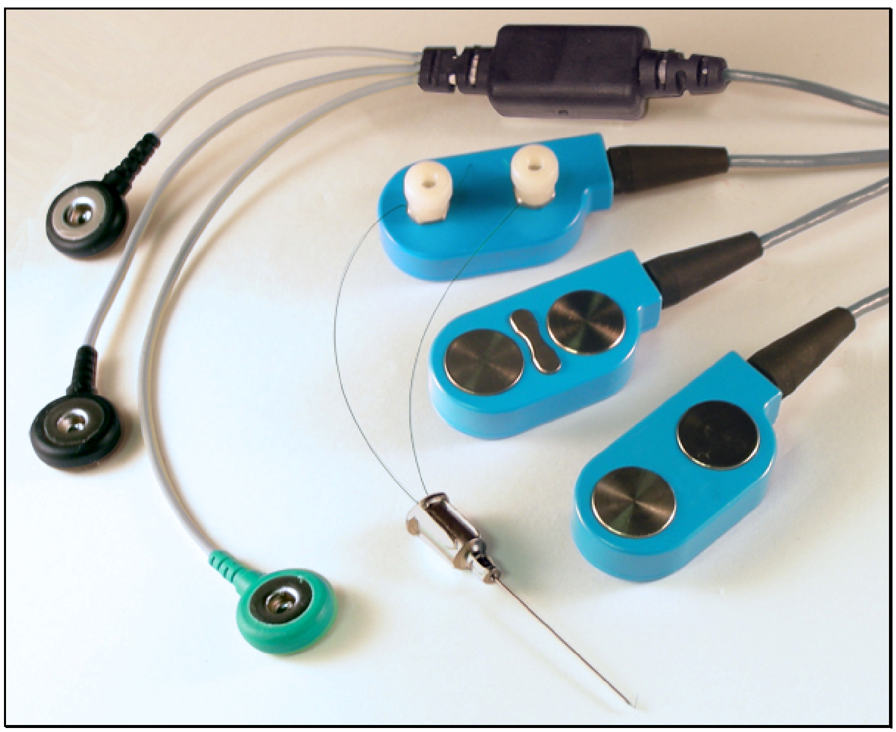


Figure 24- EMG preamplifiers are available in many different packages.

Another important characteristic of the amplifier is the bandwidth. This is simply the range of frequencies that the amplifier will pass. This needs to be selected to reject the low frequency movement artifacts and to attenuate the EMG signal as little as feasible. In practical terms, this means that the preamplifier should operate over a minimum range from 10-20Hz to 500 Hz for surface electrodes and 2Hz to 1,500 Hz for fine wire electrodes. Using the Nyquist Theorem, this means that one must

sample at a minimum of 1,000 Hz for surface electrodes and 3,000 Hz for fine wire electrodes in order to assure capturing the entire signal. In general, we recommend that the minimum sample rates are at least 50% higher – 1500Hz for surface EMG and 4500Hz for fine wire EMG unless the EMG system frequency response is restricted to ensure that the sampled EMG signal has a reduced high frequency response.

While it is possible to process the recorded EMG data with software to filter movement artifacts after collection, it is usually more practical to take precautions to reduce the amplitude of any low frequency motion artifacts at the preamplifier by limiting the low frequency response. This can greatly reduce the amplitude of any motion artifacts and prevents large artifact signals from saturating the amplifiers, causing intermittent loss of signal. When making decisions about filtering it is important to make sure that any filter applied to the EMG signal has a low phase shift – in a perfect world, all applied filters should have zero phase shifts.

Fine Wire Electrodes

Ready to use fine-wire electrodes can be purchased in sterilized packs from Motion Lab Systems, Inc.

At one time it was common for many motion and gait analysis laboratories make their own fine wire electrodes using instructions provided in "Muscles Alive" by Basmajian and De Luca (1985) and many experimenters still make their own electrodes. However, most clinical users find it more convenient to purchase pre-sterilized fine-wire electrodes any one of a number of commercial manufacturers.

The general procedure to make fine wires electrodes is to use two lengths of wire, and flame one end of each with a heat source. This removes, or loosens the enamel so that it can come away with gentle rubbing. The bare ends of the wire are then cut back to be about 2-3 mm long. The two wires are then threaded through an intramuscular needle Needles (25 gauge, 38mm). The bare ends are turned back round the tip of the needle and the whole assembly is then sterilized in an autoclave.

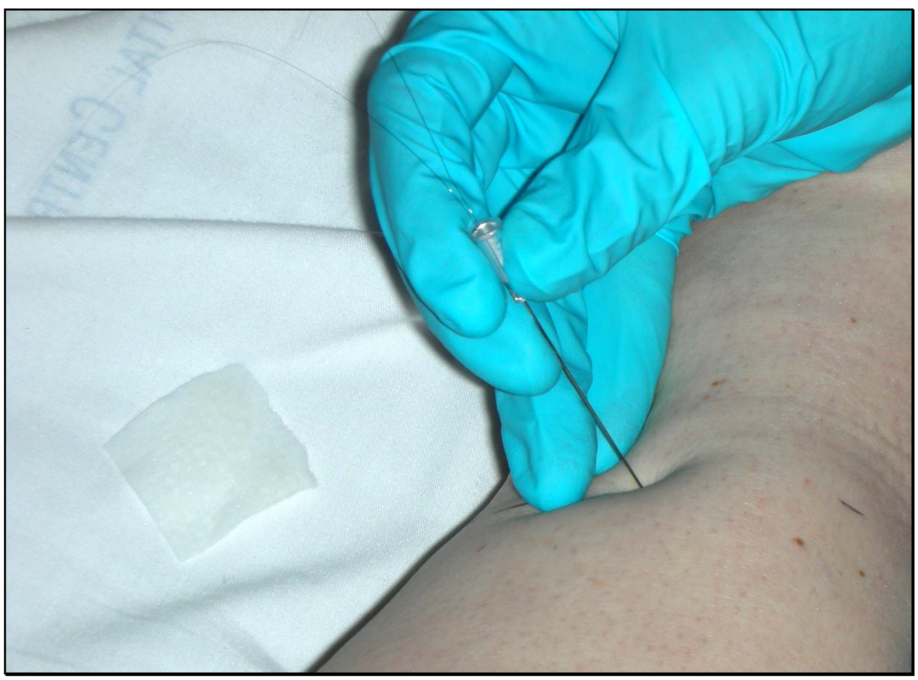


Figure 25 – Preparing to insert the needle carrying the fine wires.

For good quality signals it is important to use a separate ground reference electrode when making fine wire recordings.

In use, the needle is inserted into the muscle to position the tips of the wire within the belly of the muscle – the needle is then withdrawn, leaving the fine wire electrodes in place. The two ends of the wire outside the muscle are then connected to the pre-amplifier inputs, making sure that any motion of the subject will not pull on the inserted wire. Make sure that you remove any insulation on the free wire ends before connecting the wires to the preamplifiers.

Fine wire electrodes are usually used in controlled situations. These would include assessing a function of a muscle, which is only accessible by the indwelling electrode. These electrodes have the advantage of minimizing cross talk but this method of collection does raise the issue of whether the sampling area is representative of the whole muscle function. The small pickup area makes it more suitable to detect individual motor unit action potentials. Of course, there is added discomfort to the subject when using indwelling electrodes that may affect the subjects' behavior and it may not always be practical for regular use in a clinical setting.

Figure 26 - The insertion depth depends on the muscle location and needle length.

The advantages of fine wire electrodes are an increased band width, a more specific pick-up area, ability to test deep muscles, isolation of specific muscle parts of large muscles, and ability to test small muscles which would be impossible to detect with a surface electrode due to cross-talk. The disadvantages are that the needle insertion causes discomfort, the discomfort can increase the tightness or spasticity in the muscles, cramping sometimes occurs, the electrodes are less repeatable as it is very difficult to place the needle/fine wires in the same area of the muscle each time. Additionally, one should stimulate the fine wires to be able to determine their location, which increased the discomfort of using this type of electrode. However, for certain muscles, fine wires are the only possibility for obtaining their information.

Surface electrodes are generally used to detect EMG signals consisting of the electrical activity from numerous individual motor units within the pickup area of the detection surfaces. They are easy to use and are not invasive – most subjects do not find them uncomfortable as they are simply taped to the subjects' skin surface.

Monopolar vs. Bipolar

Differences between the recording of surface and fine wire electrodes, in part, are related to the differences in the bandwidths. Fine wire electrodes have a higher frequency and can pick-up single motor unit activity as the fine wire electrode bandwidth ranges from 2-1,000 Hz, whereas surface electrode bandwidth ranges from 10-600 Hz. Whether using surface or fine wire electrodes, there are some electrode configurations that can also decrease unwanted noise.

A monopolar electrode is the easiest as it is a single sensor and a ground. However, this arrangement picks up more unwanted signals than any of the other potential configurations.

Bipolar arrangements are widely used in movement analysis. In this arrangement, there are two active electrodes and a ground. The process is to look at what is common with the two active electrodes, determine that this is noise, and throw it away, keeping what is different in the two electrodes as the signal of interest. This is termed a differentially amplified system and is less prone to interference from adjacent and deeper muscles.

A third arrangement is that of a double differentiated system. This is a system that has three active electrodes and one ground, therefore, possessing the ability to have two pairs of bipolar signals, which are then again differentially amplified. This gives a smaller pick-up area, therefore, even less noise than the bipolar electrode by itself.

Crosstalk

In addition, the issue of crosstalk also needs to be considered. Crosstalk is the recording of activity from a muscle, other than the one under investigation at the recording site. This can occur at three places; collection, processing, and recording of the EMG signal.

Crosstalk at the data collection point is primarily a problem with surface measurements. If a surface electrode is not placed directly over the belly of the muscle, or the muscle generates only a very weak signal compared to other muscles close by, then you may see crosstalk in the recorded EMG signal. This type of problem can be very difficult to detect. Generally you will find that the recorded EMG signal level is lower than expected and, in any activity involving repetitive motion, the EMG signal timing is out of phase with the expected timing for the muscle in question.

Crosstalk during the signal processing is a problem within the EMG system itself – this is usually fairly easy to spot in multi-channel systems as the EMG signal from one channel will appear (often at a lower level) in all other channels. Contact your EMG system manufacturer to arrange for repair if you suspect that you are seeing crosstalk within your EMG system.

Finally, crosstalk during data recording can be a problem with almost any kind of data recording system. Generally, crosstalk during recording (or data sampling with most modern digital systems) results in a signal in one channel appearing in one or more adjacent channels. Depending on the system design, a signal in channel *n* will typically appear in channel *n+1* but not in *n-1*. This often indicates a data-sampling problem in computer-based ADC recording systems.

Making EMG Recordings

Preparation

The electromyographer must have a very good understanding of the anatomy of the human body as electrode location and placement is very important if a good quality EMG signal is to be obtained. First, make sure that the surface of the skin is clean in order to reduce any skin resistance and allow surface preamplifiers or gel electrodes to be attached without coming loose. The skin over the muscle should be warm and supple without any dry or loose flakes – if you are using surface preamplifiers then rubbing a *small amount* of lotion or electrode gel into the surface of the skin prior to the placement of the electrodes can reduce the resistance of the skin by 200% and improve the quality of the EMG signal by a similar amount. Some researchers recommend additional preparations including shaving and abrading the skin surface to obtain even lower skin resistance but this is almost never required for short-term (individual recording sessions of less than one to two hours) studies.

For almost all clinical EMG applications, the best signal is obtained when the electrode is placed directly over the belly of the muscle. To assure repeatability of finding the specific site for the electrode various bony landmarks are often used as a reference – this technique, among others, is described in numerous books and publications. Another widely accepted method of locating suitable EMG signal locations is the use of the motor point.

When using discrete electrodes you must also consider the inter-electrode distance and make sure that this distance is consistent throughout all subjects and trials to assure that the electrodes are over the same muscle fibers in each subject. This step can be skipped if you are using pre-amplified surface electrodes, such as supplied with our EMG systems as these have fixed electrode geometries.

Noise Sources

Good techniques and careful preparation before an EMG recording session will eliminate most forms of noise.

There are many sources of noise that can appear in an EMG study – almost any unwanted signal collected along side the wanted signal is “noise” even though it may be a perfectly valid signal (e.g. pacemaker or EKG signals). Some of the more common noise sources are: electromagnetic fields (power lines), motion artifact due to loose electrodes at the skin interface or loose leads on the wires, involuntary reflex activity (clonus), and any other electrical device that might be either in the room, or close by, when the EMG studies are occurring.

The majority of noise artifacts can be prevented by a few simple means. Proper cleaning of the skin is one such measure that is particularly critical if pre-amplified

electrodes are not used. Using bipolar differentially amplified or double differentially amplified systems also help dramatically in the removal of artifacts from the system by eliminating signals that are common to both electrode inputs. Securing all loose electrode leads and making sure that there is some slack in these leads is important as well so that the electrodes on the recording site are not moved or stressed during the recording. Before the starting data collection, check that the electrodes are making proper contact, that there is no tension on the wires, and that all of the wires are plugged into all connectors correctly.

Always perform a Manual Muscle Test to verify the correct electrode placement on the muscle.

Once the electrodes are in position, the subject should have manual muscle tests applied for the specific muscles being tested to make sure that the EMG electrodes are picking up muscle activity appropriately. If certain electrodes seem to be working inappropriately, you can try switching the leads (if using discrete electrodes), or just switching electrode channels to see if this particular electrode works in another channel. If the signal is still bad after switching channels, then switch electrodes to see if the electrode itself is malfunctioning.

When testing different subjects it is important to remember that there is an attenuation of the EMG signal as the amount of adipose tissue over the muscle being examined increases. Therefore, it may be difficult to pickup normal EMG signal levels when dealing with obese individuals when using surface electrodes. Furthermore, do not fall into the trap of assuming that the measured EMG signal is proportional to muscle mass – EMG signal level is affected by many different factors but in the end, an active muscle will generate a larger signal than an inactive muscle.

Checking the EMG signal

Monitoring the EMG signal in real-time, as the muscles contract is an invaluable tool that will enable you to improve the EMG signal quality.

It is imperative that the raw EMG signal can be monitored in real-time, as it is recorded and as the electrodes are placed on the subject. Ideally, this monitoring must be performed as the EMG signal is recorded as it is often difficult to differentiate between signal and noise if any processing has been done to the EMG signal. One disadvantage of using some computerized collection systems is that many do not provide the ability to see a raw EMG signal in real time. In this case we recommend using a separate EMG display system.

A novice electromyographer may have some trouble determining if any problems exist in the raw EMG signal. However, there are several items that can be quickly spotted - a wavering base line is a common indication that low frequency movement artifacts are present. Large, individual spikes can be also indicative of motion of the pickup electrode on the skin surface. Other things to look for are common signals across all channels (possibly a poor ground reference electrode) and/or an underlying 50 or 60 Hz line power signal superimposed on the signal. If the EMG signal does not look clean then we recommend that you attempt to fix the cause of the problem before deciding to filter the recorded EMG data. It is always better to fix the problems that cause artifact rather than attempting to filter the data after data collection.

Filtering the EMG signal

Filtering is the process of removing information from the recorded EMG signal. Use it cautiously!

There are two basic filters that can be applied to EMG signals – high-pass (passes the higher frequencies and attenuates lower frequencies) and low-pass (passes lower frequencies and attenuates higher frequency signals). Other filters such as notch and band-pass filters are just combinations of these two basic filters. Each of these filters comes in a range of different types such as Bessel, Butterworth, and Chebyshev etc.

Traditionally Butterworth filters are used to process EMG signals as this filter type produces relatively little phase and amplitude distortion in the EMG signal – in addition, in the days when all filters where built with integrated circuits and transistors, Butterworth filters were relatively easy to design. With the advent of digital signal processing other filter types have become available but in general, if EMG data is going to be filtered then you should use either a Bessel or Butterworth filter type as these introduce less distortion than other filter types.

In general, you are likely to apply a high-pass and a low-pass filter to your data. The high-pass filter will remove motion artifact and other low-frequency noise from the EMG signal while the low-pass filter will remove unwanted high-frequency noise. Both the ***EMG Analysis*** and ***EMG Graphing*** programs include separate, user adjustable high and low pass filters that can be applied to the EMG data.

Careful preparation and attention to recording a clean EMG signal from the subject will often eliminate the need to filter the recorded EMG signal.

Most EMG data is high-pass filtered at 10-15 Hz or higher, depending on the activity (10 Hz for normal walking and 15 Hz for more rapid movements) to remove movement artifacts. Clinical EMG data is usually low-pass filtered at 300-600 Hz for surface EMG, or 1,000 Hz or higher for fine wire EMG recordings. The choice of whether to filter the data or not, and the filter points to use, depends partly on the quality of the raw data and partly on the intended use of the processed data. If you are collecting EMG data for research then you should filter the data according to your research protocol – document the filter settings carefully and, if at all possible, archive a copy of the original (unfiltered) data.

EMG data for clinical motion analysis use tend to be more heavily filtered – partly to remove motion and other artifacts that may be unavoidable in clinical subjects, and partly because the timing of muscle activity is (in most cases) more significant than the fine details of the content of the EMG activity.

It is occasionally necessary to add an additional notch filter to remove line frequency noise (50/60 Hz signals depending on the line frequency in your country) but in general, this type of interference indicates a problem with your EMG equipment (possibly a loss of Common Mode Rejection) that should be investigated to eliminate this type of noise. Both the ***EMG Analysis*** and ***EMG Graphing*** programs include a user adjustable notch filter designed specifically to remove AC line noise if it is a problem.

Analysis techniques

Once we have a clean EMG signal, we can begin to look at the data and try to figure out what it is telling us about the muscles. The primary information to be gained is timing (on/off) information. In most movement analysis situations this timing information can be read directly from the raw EMG signal, no processing other than that which is used for cleaning up the raw signal (high and low- pass filters) is required.

However, there are many common forms of processing that are done with EMG signals. The most common are:

- Half-wave rectification (deletion of all negative aspects of the signal).
- Full-wave rectification (absolute value of the entire signal).
- Linear envelope (low-pass filtering of the full-wave rectified signal).
- RMS or root mean square (basically square the signal, take the mean of a timed determinant window about 100-200 ms, then take the square root).
- Integrated EMG (area under the rectified curve can be determined for the entire activity or for pre-set time or amplitude values).

- Frequency analysis (typically determined via fast Fourier analysis and looking at the power density spectrum).

Depending on your application, each of these processing techniques may have merit but each have disadvantages as well, since with any processing done to the data, information is lost.

For comparisons of EMG data from task to task or person to person, the data needs to be presented in a common format. Several means of normalization of the signal have been developed for both the time and amplitude domains - probably the two most widely used time-base normalization techniques are to either normalize to a task/cycle or to phases within the task/cycle.

As an example lets assume we want to look at the EMG of the back muscles with an individual who continually lifts items from the floor and places it in a bin. We can define a cycle as being from the initial movement of the object off the floor until the initial movement of the object off the floor for the successive lift. One would then just simply divide the time-base by the total amount of time it took to perform the task and then all movements would be with respect to the percent of the cycle. This works well for many cyclic tasks, but has disadvantages if the task contains more than one phase. Dividing the time-base to the percent of a phase works well for task with multiple phases.

Using the same lifting task, let us now define the lifting phase as being from the point that the object begins to move from the floor until the subject obtains a fully erect standing position. The second phase would then be from the point at which the subject reached the standing position until the item is placed in the bin and a third phase would begin at the point when the object was placed in the bin until the subject is back in position to lift another object.

Each one of these phases is handled as a separate event. Thus, the time it took to lift from the floor to the standing position would be used as the divisor to make a percent phase for the lifting phase, the time it took from the point when the body reached an erect standing position until the item was in the bin would be used as the divisor for the second phase, and so on for the third phase.

This type of time-based standardization is very useful when the task has clear phases that can be determined. For the sake of this example, let's say that the maximum EMG activity occurred just before setting the item down in the bin. It is much more meaningful to be able to say that the maximum amount of the EMG was found at 95% of the second phase than to say the maximum EMG was found at 55% of the task. From this point, you would have to go back and figure out what movement was going on at 55% of the task. Additionally, the intra and inter subject variability of setting the object in the bin at the same point in a multiphase cycle is typically large. For this reason, most people prefer to use percentages of phases of action whenever possible.

Amplitude Normalization

Many times the amplitude of the signal is normalized as well. Probably the most widely used is to standardize to the maximum voluntary isometric contraction (MVIC) for the specific muscle being used. Based upon published references for manual muscle testing, the examiner then applies a force to the body part in sufficient magnitude that the subject is unable to maintain a static position while exerting against the examiner with a maximum muscle contraction. This is fine in theory but in practice, it is debatable if it is possible to obtain a true MVIC that is consistent between subjects and examiners - therefore, several other techniques have been devised.

One of those is to use the maximum level of the signal across the entire task. In the lifting task previously described, this would mean to take the maximum EMG level from each specific muscle during the entire task then normalize to this value. Usually several peaks (three or more) are used – these are averaged to avoid the potential of using an erroneous high-spike as the maximum value.

Another means of normalization is to use the mean level of the signal across the entire task. However, this is much less sensitive to any rapid peaks that were obtained during the task and would heavily skew the data if the majority of the signal contained times when the muscle was not active.

A problem that exists when using the maximum or mean level across the entire task is that the EMG signal will vary based upon the velocity of the joints during the contractions. Therefore, unless one standardizes the velocity of the task, this method may not allow for comparisons across tasks.

Another technique very similar to the MVIC is to use a known level of force (e.g., divide by the amplitude of the EMG when lifting 20 lbs. at the specific velocity that the task will be performed). Another variation of this is to use the amplitude of the EMG signal when exerting a known force against an immovable object, therefore, eliminating velocity from the equation. All of these methods have positive and negative attributes and they are means of trying to compare amplitudes between muscles and individuals.

Additionally, if the subjects being examined have any pathological conditions that involve the muscles you are testing it will be virtually impossible to get a true MVIC and questionable whether the other normalization techniques are of any value as well. Regardless of the normalization technique used, whether it is time-based and/or amplitude based, one must remember that absolute information will be lost.

Caveats

The word *caveat* is Latin for *"let him beware"* **-** now that we have cleaned up the EMG data and completed any normalization that we may want to do, it is time to look at the processed signal and try to interpret its meaning. It is very important to understand that there is a large variability of the EMG signal itself. Whether this is task-to-task variability within the same person, or person-to-person variability within the same task, many combinations of muscle activity can produce the same movements because of the redundancy present in the neuromuscular system. EMG can be variable from task to task because of this normal redundancy, velocity or cadence changes, or slightly different movement patterns even though under observation they look the same.

A normal range of EMG phasing will exist for a task but one must be very cautious of trying to define discreet points in the tasks where these patterns begin and end. This must be kept in mind when interpreting the EMG signals. Other factors enter into the equation with interpreting the EMG of individuals with pathological conditions that influence the task-to-task variability. The changes in velocity or cadence, the onset of fatigue, and the presence of pain can all affect the EMG patterns.

Another factor, which makes interpretation of the signal difficult, is cross talk. Cross talk is interference of the EMG signals from adjacent muscles or deeper muscles that are within the pick-up area of the electrode. There are no fixed solutions available at this point and the size of the patient and size of the electrode lead does play a major role in the ability to decrease or increase cross talk. For example, if your system has electrodes with fixed active electrode distances that are large and you are working with a pediatric population you can be assured that your data will have large amounts

of muscle information from adjacent and underlying muscles that is not wanted with your data. Many physicians utilize fine wire electrodes in order to try to remedy this problem.

Interpretation

Now that we spent much time filtering and normalizing our data, it is time to discuss what the EMG signal can actually tell us. The muscle on and off timing patterns and relative increases and decreases in muscle activity are the two main parameters gained from the electromyography data. EMG data alone cannot tell us how strong the muscle is, if one muscle is stronger than another muscle, if the contraction is a concentric or eccentric contraction, or if the activity is under voluntary control by the individual.

The normalizing to the MVIC, the average, or the maximum level during the cycle are all attempts to allow us to be able to compare from muscle to muscle within the same person and from muscle to muscle between individuals. These are all common methods that attempt to make the EMG data produce results that allow us to compare contractions in-between subjects or activities but one must be cautious of interpreting the results due to the problems inherent with the collection techniques and the natural variability among muscles, individuals, and tasks.

Besides using EMG for determining the EMG patterns (times of activation and times of rest) many researchers use electromyography for evaluating the changes in the signals as the muscles fatigue or alternatively, to evaluate the change in tone and strength as muscle strengthen through exercise and physical therapy. All of these are valuable uses of electromyography in occupational biomechanics.

Application

Whenever using EMG for clinical or research purposes, care should be taken to ensure that you always use a common environment to collect and record the data and that the conditions be documented to allow others to reproduce your results.

This is especially important in the research environment where you should ensure that you use appropriate units when reporting EMG data. In particular, when referring to the amplifier gain, the units should be in a ratio or dB, and the input impedance should be expressed in ohms (e.g. $1x10^6$ ohms).

The common mode rejection ratio should always be stated, either as a ratio or in dB. The measured bandwidth of the signal should be stated in Hz – usually indicating the –3dB point of the processed EMG signal but it is important to indicate the flat portion of the signal bandwidth if at all possible.

The EMG level, when a raw, average or rectified signal, should be referred to in millivolts (mV). If the EMG signal has been integrated, then it should be expressed in terms of millivolt-seconds with the specific period of analysis. If the integrated EMG was time reset or voltage reset, then the specific time or voltage should be indicated. By clearly stating the precise environment used for data collection and data processing, you will enable others to reproduce the study that you have conducted.

EMG data collection from clinical analysis should always be performed in a comfortable environment for the subject. The room should be warm and well ventilated to eliminate shivering and sweating as sources of artifact and poor signal quality.

Surface EMG

This is the most common form of EMG recording in most gait and biomechanics environments – it involves the placement of two or more electrodes (often in a single physical package) on the surface of the subjects' skin. It is easy to use, required very little preparation and produces good results for large muscles that are close to the surface. It is inappropriate for EMG signals from deep muscles, or from muscles that lie underneath other muscles.

Preparation

Use alcohol or a similar non-oily cleansing solution to removal of dirt, oil, and dead skin. Shave excess hair if absolutely necessary but this is not normally required – most research studies that state that shaving is *required* can trace this assumption to animal research (e.g. with felines).

If the skin surface is dry, some electrode gel rubbed into the skin can dramatically improve the quality of the recorded signal provided that the amount used is very small – the skin surface should be wiped clean after applying the gel to make sure that none remains on the surface of the subjects' skin.

Placement

There are several specific references for different ways to measure the subject for electrode placement. The general guidelines for large muscle groups are that the electrodes should be placed over the largest mass of the muscle and aligned with the muscle fibers - use a motor point and motor point finder to locate these if you are not an experienced electromyographer.

Crosstalk

Intramuscular cross-talk is always a possibility with surface EMG recordings but is not usually a problem with clinical data collection from large muscle groups. Cross-talk can often be avoided by careful placement or by adjusting the electrode size and inter-electrode distance if you are using discrete electrodes.

Application

Skin placement techniques are all important when using surface EMG electrodes. It is vital that you prevent any movement of electrodes against the skin surface by using straps or tape to firmly secure pre-amplified electrodes in place or by ensuring that discreet gel electrodes are firmly affixed to the skin surface.

If using discreet gel or reusable electrodes then avoid bending the electrode leads in any way that might place a stress on the electrode during motion. Place the leads pointing in the direction that you want the wire to continue (e.g., for electrodes placed on an extremity, have the lead pointing towards the proximal end of the extremity so that the wire will not have to be bent in order to go in the proximal direction.)

Avoid any stress on the electrode wires by making sure that the wires are loose underneath the tape or wrap that is holding them in place. Be sure to check when the wires cross the joint that once the joint is fully extended the wires are not drawn taunt – this could place strain (and thus cause artifact) on the electrode/skin interface. Finally, avoid placing electrodes over scars.

Testing

It makes little sense to spend the time to record EMG if you are going to be in any doubt about the validity of the recorded signal. You should always perform a manual muscle test to ensure that you are getting a signal and that you are over the intended muscle – this should be part of your standard Quality Assurance and is very useful if questions arise later as to which muscle has actually been recorded.

Once you are confident that your electrodes are correctly placed, you should record a pre-trial session to check the EMG signal and to get the subject used to the setup and instrumentation. This trial session should be preserved as part of your control documentation – you may also wish to record and save an additional post-trial session after all the EMG tests have been performed to document any conditions or problems that may have occurred during the EMG recording session. If the recorded pre-trial and post-trial sessions are comparable then you can be confident of the session data.

Fine Wire EMG

Fine wire EMG is an invasive procedure and may be a legally regulated procedure in your jurisdiction. Always consult your physician or administrators for clarification before performing any fine-wire insertions on subjects.

Fine wire EMG involves the insertion of a pair of wire electrodes into the muscle body, usually via a needle, which is withdrawn once the wires are in place. Fine wire EMG is appropriate for small muscles, deep muscles that not accessible by surface electrodes, and to isolate specific muscles from a muscle group or adjacent muscles.

Preparation

Use alcohol or a similar non-oily cleansing solution to removal of dirt, oil, and dead skin. It is not necessary to shave excess hair for fine wire insertions unless it is required to enable the researcher to locate the insertion site with precision.

Paired fine wire electrodes can be constructed as described by Basmajian and others, or purchased from a number of commercial sources including Motion Lab Systems. Fine wire electrodes are usually available with various canella lengths – make sure that you use fine wire electrode with sufficiently long wires for any study involving motion. The two wires typically connect to a local pre-amplifier or to fine wire connectors (springs, clips etc). In general some type of ground reference is used.

If desired you can use various topical agents to control pain associated with the needle and wire insertion. Typical agents are Ethyl Chloride - a vapocoolant (skin refrigerant) intended for injections and minor surgical procedures, and EMLA (lidocaine 2.5% and prilocaine 2.5%) a topical anesthetic for use on normal intact skin for local analgesia (pain relief). EMLA is contraindicated in patients with a known history of sensitivity to amide based local anesthetics.

Unlike surface EMG applications, an assistant is generally required for fine-wire applications to help in preparation, stabilize the extremity, or distract the subject during the insertion procedure if needed (having the subject blow out forcefully as the needle is inserted works well). It is usually easier to have the subject lying down, and the muscle relaxed, for insertion of the fine wire electrodes. Needless to say, clinical cleanliness, washing of hands and universal precautions are in order for this procedure.

Placement

There are several specific references for different ways to measure the subject for electrode placement, the use of a cross sectional anatomy book or EMG guide to locate insertion point and the direction of application is highly recommended e.g. "Anatomical Guide for Electromyography: The Limbs and Trunk."

Always check the placement of the fine wires with either electrical stimulation or by manual muscle testing. Note that manual muscle testing is not a particularly useful test if the same movement needed for testing the selected muscle would activate adjacent muscles.

After inserting the fine wires and removing the needle secure the wires to the preamplifier or electrode clip. Then tape the wire in place to the skin with small loop of wire to allow for movement. Make sure that any motion of the subject will not strain the wire at the insertion site, as this will cause artifact during data collection.

It is a good idea to recheck the placement of the wires via electrical stimulation or manual muscle testing if questions arise during the collection process.

Crosstalk

Intramuscular cross talk is not usually a problem with fine wire recording if the fine wire electrodes are placed correctly. However, incorrect placement can produce crosstalk symptoms if the wires are either too deep, too shallow, or have missed the body of the muscle in any way.

Removal of the wires

You can remove the wires after the testing has been completed by gently pulling the wires out of the muscle. Check the ends of the wire to assure that no significant lengths of wire have broken off inside the body.

Sharps canisters are required for disposal of fine wire needles. For disposal of the wire and gloves, you should check with your infection control or OSHA office to determine what needs to be done at your facility to determine if a biohazard container must be used.

EMG Data Collection

It is preferred to do a minimum of processing of the EMG data during the data collection, as it is difficult or impossible to know if noise has corrupted your data before the processing. Some general rules are:

- Record surface EMG signals at a sample rate of 1,200 samples per second or higher for a recording bandwidth of at least 600Hz. It is recommended that research quality data is sampled at least four times higher than the desired frequency response.
- Record fine wire EMG signals at a sample rate of 3,000 samples per second or higher for a recording bandwidth of at least 1500Hz. It is recommended that research quality data is sampled at least four times higher than the desired frequency response.
- Use a high-pass filter (prior to data sampling) with a cut-off of 5-15 Hz to remove motion artifact components from the EMG signal. The precise high-pass filter frequency depends on the subject activity – vigorous physical motion may require higher filter frequencies of 25 to 45Hz to remove all motion artifact.

- A low-pass filter (prior to data sampling) at 500-600 Hz for surface EMG and 1,000-1,500 Hz for fine wire EMG works well as an anti-aliasing filter. These filter frequencies must be decreased if your sampling rate is lower than the recommended rates listed above. Use high quality Butterworth or Bessel filters for all low pass filtering.

It is highly recommended that any EMG data collection system provide a means of monitoring all of the EMG signals in real time via some form of multi-channel display. This allows any signal quality problems to be quickly detected and fixed prior to sampling and recording the EMG signals.

Remember that all EMG signals are basically MUAP pulse trains so a good high frequency response, pulse and transient response are essential in your EMG system if accuracy and quality are important.

EMG systems manufactured by Motion Lab Systems meet all the requirements described above.

Signal Analysis methods

Analyzing EMG

The timing of muscle activity can be easily determined from the raw EMG. The onset and cessation of EMG activity can then be correlated to the stance and swing periods of gait. The difference in the EMG amplitude of a single muscle represents varying levels of activity. As more muscle strength is required, additional motor units are added, thus visually the EMG signal has larger amplitude and becomes denser.

Normalization of the EMG signal amplitude is required when attempting to compare the signals from different muscles. One simple method of amplitude normalization is to normalize each of the displayed EMG channels to the maximum of the signal throughout the current trial within the channel. Thus, the muscle effort can then be displayed as a simple percent of the maximum achieved by that muscle in the current trial – this a simple method that works very reliably for most common EMG signals. This type of EMG signal normalization is called *Amplitude Normalization.*

An alternative normalization method is to make an individual recording from each muscle, while the subject is attempting to generate a maximum contraction for the individual muscle (or muscle group). Each EMG channel is then normalized to the maximum amplitude of the recorded EMG signal during the test. This method is more complex and time consuming than the simpler *Amplitude Normalization* method but is considered to provide a more accurate comparison of the recorded EMG signal. The type of EMG signal normalization is called *Maximum Voluntary Contraction Normalization* – often abbreviated to MVC.

The Motion Lab Systems ***EMG Analysis*** or ***EMG Graphing*** programs support both the *Amplitude Normalization* and *MVC Normalization* methods.

In addition to the Normalization methods discussed above, the ***EMG Analysis*** or ***EMG Graphing*** programs also support several *calibration* modes that enable the EMG signals to be scaled to a fixed reference. Typically the raw EMG signal is scaled in terms of "Volts at the ADC input" but both the ***EMG Analysis*** and ***EMG Graphing*** applications support scaling by inputting a known signal level or by entering a channel gain factor for each individual EMG channel. These methods are called *File* and *Gain Switch* calibration respectively – each method enables the EMG analysis and Graphing results to be displayed in terms of *Volts at Skin Surface*.

Time Normalization

In almost every practical measurement situation, each gait cycle or EMG measurement (or data collection) period lasts for a slightly different length of time. As a result, we cannot compare the EMG levels from sample *'n'* in one measurement period with the same sample *'n'* in another period – if the lengths of the measurement periods (gait cycles) are different then the two samples may occur at very different points in the EMG contraction cycle. As a result, the different duration of gait cycles is a major concern while averaging or comparing EMG data from several different gait cycles. For this reason, both the ***EMG Analysis*** and ***EMG Graphing*** applications support *Time Normalization.*

In order to make a valid comparison of EMG data across various gait cycles we must find a way of making each cycle or measurement period identical – this process is called *Time Normalization*. For example, a normal adult subject walks at about one stride per second, thus the duration of a gait cycle is approximately one second – give or take 200-300ms from one heel strike event to the next heel strike event. Thus, each period of EMG data will contain a different number of data samples, making comparisons between repetitive actions (such as walking) very difficult.

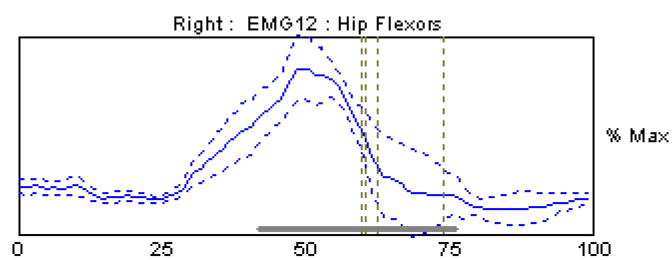


Figure 27 - Time Normalized data from several gait cycles.

Time Normalization of repetitive periods of EMG activity results in each EMG activity period being re-sampled to contain the same number of data samples which allows data from any given point in one measurement period to be compared to the data occurring in another period at the same percentage of the gait cycle or EMG event define period. Generally *Time Normalized* data is plotted as a percentage of the event period or gait cycle, allowing different EMG periods to be averaged and compared with confidence.

Amplitude Normalization

EMG signal quality and quantity are influenced by factors like instrumentation, amplifier gain, electrode placement, and the electrode-skin interface. Referencing the EMG amplitude to a common level for each individual is essential to validate amplitude comparisons. The most compelling reason for using amplitude

normalization is to allow between subject, between day and between-muscle comparisons of EMG activity. The ***EMG Analysis*** or ***EMG Graphing*** applications support two methods of EMG amplitude normalization:

- Normalization using a maximal voluntary isometric contraction (MVIC).
- Normalization using the peak EMG during a dynamic activity.

Studies have shown that using the peak dynamic activity EMG signal results in lower inter-subject coefficients of variation (CV). Other studies have shown that normalizing to the maximal value from an isometric contraction may result in higher coefficients of variation but the values generated are more likely to be reproducible. In most cases, the major factor in the ability of the electromyographer to produce reliable results is their degree of experience and confidence with the chosen method.

Time domain analysis of the EMG signal

The EMG signal is dependent upon time and force among other factors – as a result, quantification of activity is necessary to generate valid comparisons of EMG activity between subjects. It is essential not only to know when a muscle is ON or OFF but also, what the level of activity of the muscle is at the relevant times. This presents a problem as the direct comparison between raw EMG signal amplitudes in different subjects is affected by many factors outside the control of the electromyographer.

As a result, most clinical gait or motion studies involving EMG attempt to collect multiple periods (cycles) of activity in order to generate a representative subject average, with the expectation that comparisons between averages will be more reliable than comparisons between individual bursts of activity. The ***EMG Analysis*** application supports several methods of averaging muscle activity that are of interest to researchers and clinicians.

Averaging EMG data is equivalent to smoothing the signal and results in the suppression of high frequency components of the EMG signal so that the deflections appear smoother – thus making the contractile actions of the muscle easier to observe and interpret. Averaging is always performed on the processed EMG signal – never on the raw EMG data.

EMG Signal Averaging

This method of averaging displays the way that the EMG activity changes over the period of a contraction. The ***EMG Analysis*** program supports three forms of EMG signal averaging analysis – Moving Average, Linear Envelope, and RMS Analysis. In each case, the averaging calculations are performed using the full wave rectified EMG signal.

In theory, envelope processing emulates the force development over time in the muscle so the low pass filter cut-off should generally be set to match the twitch characteristics of the muscle being studied. Various authors (Winter et. al.) have suggested a range of appropriate cut-offs for slow twitch, fast twitch and mixed muscle around 1 to 2.5 Hz. The appropriate choice of cut-off should produce a reasonable estimate of the shape of the muscle force-time curve and account for the electro-mechanical delay.

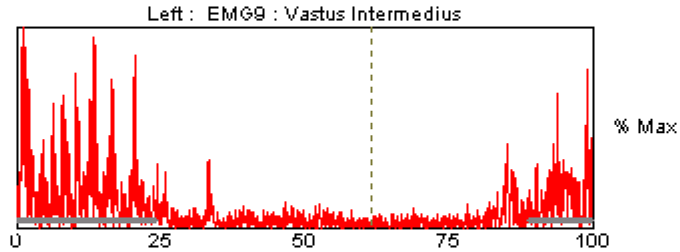


Figure 28 - Full Wave Rectified data from the Vastus Intermedius.

The Moving Average function is only available in the EMG Analysis application.

The *Moving Average* function calculates the absolute value of the full wave rectified EMG signal over a window of time specified in milliseconds – typically, values in the range of 50 to 250ms are used. The graph below shows the results after performing Moving Average analysis with a 150ms window,

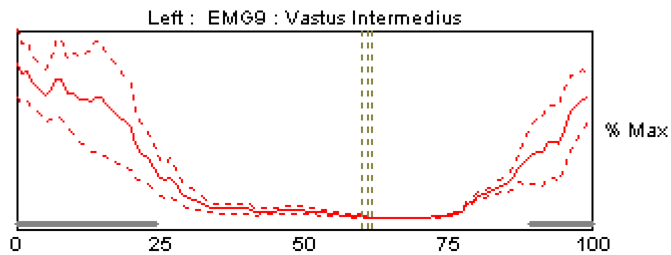


Figure 29 - Moving Average analysis of the Vastus Intermedius.

The Linear Envelope function is only available in the EMG Analysis application.

The *Linear Envelope* function processes the full wave rectified EMG signal with a low pass filter – typically using filter frequencies between 6Hz and 12Hz. The user can select either a single pass or dual pass filter. The dual pass filter option applies the digital filter to the data twice and effective eliminates the time-shift that is inherent in single pass and analog filters while lowering the effective filter frequency.

The example shown below used a 6Hz, dual pass filter. Note that while this example appears to be somewhat smoother than the Moving Average analysis show above, this is simply a result of the choice of a relatively shorter averaging period (150ms) versus a lower frequency (6Hz) dual pass filter and is not directly related to the choice of analysis methods.

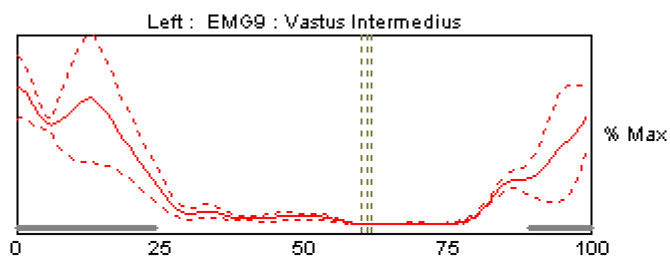


Figure 30 - Linear Envelope analysis of the Vastus Intermedius.

RMS Analysis

The *RMS Analysis* function performs a more sophisticated form of averaging than either the Linear Envelope or Moving Average methods and is generally considered to produce more reliable results with a wide range of data.

The RMS Analysis function is only available in the

The raw EMG data is initially processed through a dual pass, zero delay, high pass filter, normally set to remove frequencies below 5Hz to ensure that there is no DC

EMG Analysis application.

offset in the data. The precise filter value may be set by the user. The filtered data values are then mathematically squared, generating EMG data values that contains only positive values – the mean value of this data stream is then calculated over a user selectable interval and the square root of the resulting values is displayed.

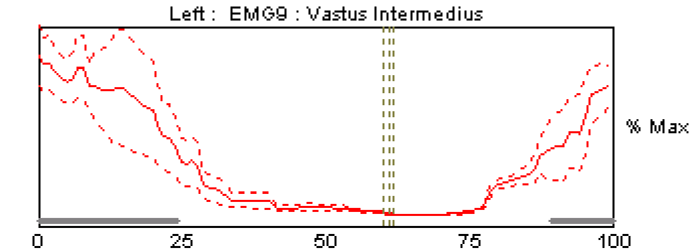


Figure 31 - RMS Analysis of the Vastus Intermedius.

Integrated EMG

Integration should, if performed appropriately, yield information about the area under the curve of the function. Because the raw EMG signal is a bi-polar signal, integration is performed on the signal of interest only after it has been full wave rectified.

An integrated EMG signal gives an indication of the activity of over a period by increasing the magnitude of the output in response to the magnitude of the input. A simple form of integration starts at some specific time and continues to the end of the period of the activity, which is not especially useful to the electromyographer in the analysis of repetitive EMG signals in a clinical environment.

The ***EMG Analysis*** program supports two forms of integration analysis – these are *Integration over Time* (resetting the integration after fixed intervals of time) and *Integrate and Reset* (resetting the integration when it reaches a specific voltage level). Both forms of analysis are strongly influenced by the selection of the integration parameters.

Integration over Time

This function is only available in the EMG Analysis application.

The Integrate over Time Analysis is performed on the rectified raw EMG signal. This process of integration over time produces an output that is proportional to the level of the EMG signal over a given period that the user can select - the data shown below has a Time Interval 20ms.

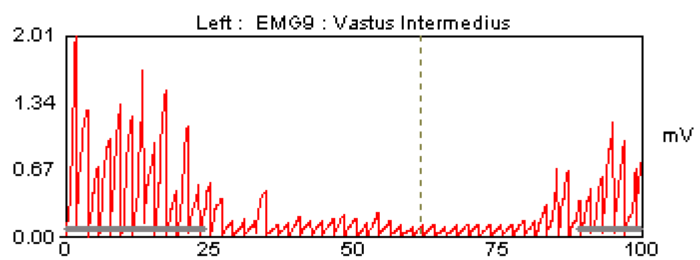


Figure 32 - Integration over time produces amplitude modulated output.

The integration process sums the rectified EMG values for the selected time period – at the end of the time period the signal output is reset to zero and the integration process restarted. Therefore this analysis produces an output that, in some degree, mimics the magnitude of the original EMG signal.

Integration and Reset

This function is only available in the EMG Analysis application.

The Integrate and Reset Analysis is performed on the rectified raw EMG signal. This process of integration and reset produces an output that is proportional to the level of the EMG signal.

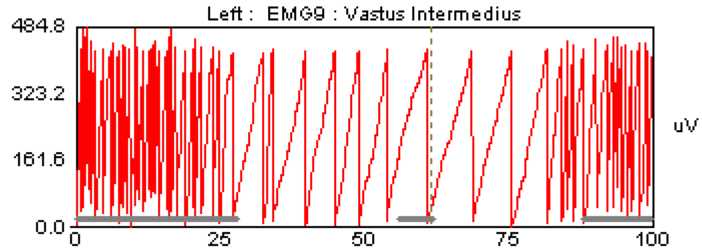


Figure 33 - Integration and reset produces a frequency modulated output.

The integration process sums the rectified EMG values until the EMG reaches a set percentage of the average level – once this level is reached the signal output is reset to zero and the integration process restarted. Thus the frequency with which the integrator resets is an indication of the magnitude of the original EMG signal with rapid resets indicating a larger EMG signal.

Frequency Analysis

Fast Fourier Transform options are only available in the EMG Analysis application.

The myoelectric signal consists of a series of muscle unit action potentials firing at a range of different frequencies. *Frequency Analysis* decomposes this signal into sinusoidal components of different frequencies enabling the direct measurement of the energy distribution of the signal, as a function of the frequency components of the signal. Essentially, this provides the electromyographer with a direct measurement of the amplitude of frequency components of the EMG signal, grouped the frequencies at which the muscles fire.

A common use of the power spectrum has been for the evaluation of local muscle fatigue. With sustained muscle contraction, the higher frequency components of the signal decrease, but the low frequency components gradually increase. This change results in a shift in the power spectrum towards lower frequencies.

Two reliable measures of the power spectrum are the mean power frequency and the median power frequency. It has been reported that the median frequency may be less sensitive to noise than the mean frequency.

The shift in the frequency spectrum may be caused by:

- Synchronization of motor units.
- Increase and decrease in the recruitment of motor units.
- Dysfunction of muscle spindles.
- Combination of synchronization and de-synchronization.
- Change in shape of motor unit signals.
- Propagation velocity changes.
- Intramuscular pressure changes.

The Fourier Transform

A Fast Fourier Transform (FFT) is an efficient algorithm to compute the Discrete Fourier Transform (DFT) and its inverse. This means that it becomes (relatively) simple to jump between the time domain and the frequency domain of a data series or signal. If the signal is a sample of the actual event, the Discrete Fourier Transform is used. The discrete Fourier transform yields a close approximation to the continuous Fourier transform. Differences between the continuous transforms and the Fast Fourier Transform (FFT) arise from discrete transform requirements for sampling and truncation. As a result, there are some issues of importance when applying the Fourier transform to EMG recordings in gait. These issues are discussed on the following sections.

Characterization of EMG signals in gait

It is important to realize that EMG signal associated with any repetitive movement contains periodic and non-periodic components. While the EMG activity may be consistent across gait cycles, it is periodic within the cycle, the signal consists of bursts of EMG activity as the muscle under investigation contracts, separated by periods of relative quiet during which the muscle is relaxed.

Thus, we cannot simply perform *Frequency Analysis* over a random interval of time that contains muscle contractions, as the periods of inactivity within the analyzed interval would seriously bias the results. Furthermore, the approach used in other areas of EMG analysis – that of looking a representative period, or cycle, and drawing inferences from it, will not work. The EMG signal from the muscle over a typical gait cycle, or other repetitive motion, contains both muscle activity (which we need to analyze) and periods of inactivity that will negatively influence the *Frequency Analysis* results if they are included.

Thus, it does not make sense, at least in a clinical setting, to try to measure the frequency content of a “trial” which consists of multiple gait cycles. Instead, the strategy is to analyze the frequency content of the intervals of the trial during which the muscle is contracting – effectively restricting the analysis to the periods of the trial during which the muscle is actually firing. The ***EMG Analysis*** program provides methods for restricting the *Frequency Analysis* to either particular portions of the gait cycle or to the periods of the cycle that contain muscle activity.

Where the EMG trial consists of multiple repetitive cycles, the electromyographer should repeat that process for all the cycles if consistency of the signal is an issue.

FFT resolution

The FFT plots are spaced in frequency by the interval,

$$f_{res} = \frac{1}{NT}$$

where N is the number of samples and T is the time between samples.

Thus NT is the length of the record whose FFT has been found. As a result, frequency samples approximating the Fourier transform are computed for nonnegative frequencies 0/NT, 1/NT, 2/NT, ..., (N/2)/NT. Because resolution is given by 1/NT, then a decrease in the frequency spacing (increased resolution) can be achieved by increasing N, that is, by increasing the truncation interval of the function to be transformed. An increase in T could result in aliasing. Thus, the resolution is determined by the width of the rectangle that multiplies and truncates the function to be transformed. This truncation in the time domain corresponds to convolution of the [sin(f)]/f function with the Fourier transform of the original time

waveform. This convolution produces a smearing or blurring of the Fourier transform. The wider the time domain truncation function, the less the frequency smear. The less the frequency smear, the better the frequency resolving power that is possible.

Appending zeroes to the end of the sampled data does not, in any way, enhance the frequency resolution of the transform. It merely provides additional frequency samples by interpolating with a [sin(f)]/f function the original frequency transform results. Adding zeroes to the function can enhance FFT resolution, if and only if, the function is zero valued over the interval where the zeroes are appended.

With reference to gait, since T is set by the maximum frequency component of the EMG signal and N is set by the time taken for a gait cycle, there is no way to increase the resolution of the transform.

FFT aliasing

One problem encountered when computing the Fourier transform with the FFT is that of aliasing. Aliasing occurs if the samples of the time function are not collected sufficiently closely together. The result is that the frequency function folds or overlaps on itself with high frequency signals appearing to be translated into signal components in the lower frequencies. This problem can be avoided by making sure that the original data has been sampled at a high enough frequency.

For optimum results we recommend that EMG data that is to be analyzed via the FFT is sampled at least four times faster than the minimum Nyquist frequency. EMG data that contains frequencies up to 500Hz must be sampled at 1000Hz to preserve the frequency content and should preferably be sampled at 4000Hz or higher is FFT analysis is to be performed.

FFT time domain truncation

Time domain truncation of the signal can be a problem if the FFT is going to be used. The problem occurs when the total number of samples chosen to characterize the time function truncates the original time waveform. This would occur if the FFT of 21/2 cycles of a 3Hz sine wave were computed. We would no longer get a single component at 3Hz but instead a “rippling” effect would be observed. Thus, if a periodic waveform is truncated in time, an integral number of its cycles should be present in the sample.

This would not seem like a problem in gait if you were analyzing a single gait cycle. However, the amount of information that would be obtained from a complete gait cycle is debatable. A muscle goes through stages of contraction and relaxation in a gait cycle and the whole cycle would not represent any single event. The appropriate action is to isolate the part of the gait cycle of interest and find the frequency content of that part of the cycle. The ***EMG Analysis*** program provides methods for restricting the FFT analysis either to preset periods within the gait cycle, or to the periods of the cycle that contain muscle activity by using other analysis techniques to isolate bursts of muscle signals.

Using your EMG program

The User Interface

When the Motion Lab Systems ***EMG Analysis*** or ***EMG Graphing*** programs are started the application window will appear - this will be blank except for a menu bar and short-cut bar that appear at the top of the window. The program responds to all the normal commands to position and control the display - it uses the mouse right and left click menus extensively to allow the electromyographer full control of the analysis and graphing in an interactive and easily controlled environment. The application can be represented on the screen in one of the three ways: full screen (maximized), as an application icon (minimized), or within a window (restored).

The name of the EMG data file that is being analyzed will be displayed in the title bar at the top left corner of the application; a menu bar is displayed below the title bar. A toolbar is (optionally) available with commonly used commands together with a frame based navigation tool that allows you to scroll through the data and control the current view of the EMG data.

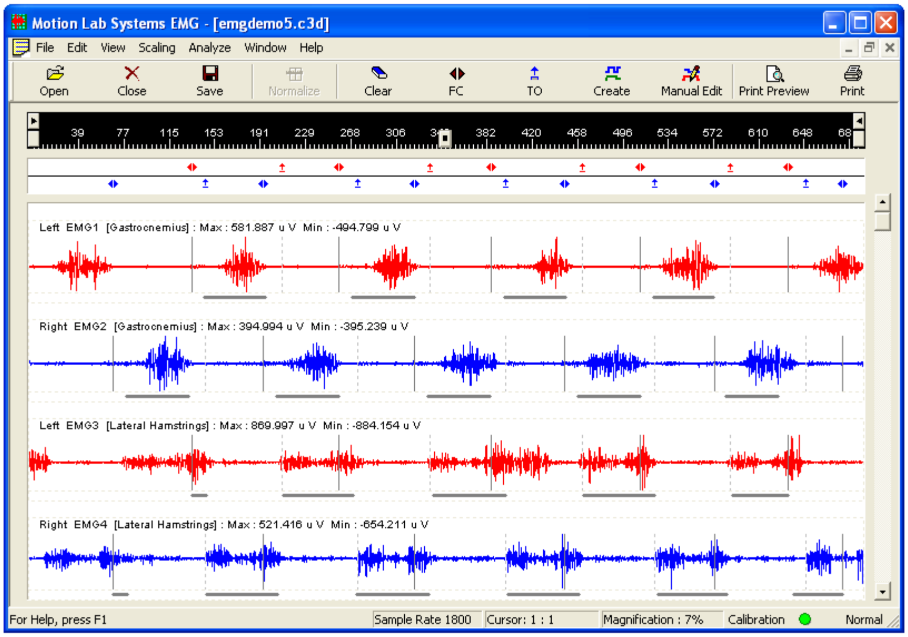


Figure 34 - Trial view of the EMG data file.

A scrollbar on the right of the display window allows the electromyographer to scroll through the channels in order. Each channel can be optionally be labeled with the side (for gait related data), a label and a description, as well as the EMG signal range – either at skin surface if the data has been calibrated, or at the ADC inputs. Channels can be color coded to indicate side – the colors used and the display of the various labeling options is fully controllable from the *View:Options* menu, which is also accessible via the mouse right-click menu.

Normal activity bars are displayed for each EMG channel if the channel description matched the values stored in the currently selected "Normal EMG Data" dialog (accessible from the Edit menu) while the gait cycle event lines, normally heel contact (start/end of gait cycle) and toe off (gait transition from stance to swing), are drawn if selected in the options "graph" menu.

The status bar at the bottom of the window displays the EMG data file sample rate, the frame and sample number for data at the cursor position and the degree of magnification of the display. Two "LED style" indicators on the far right of the status bar display the calibration and normalization status of the displayed data.

The File menu

The *File Menu* can always be selected from the left side of the Menu Bar. This menu contains commands that open and save EMG data files, commands that operate on EMG data files (Template and Automation) and commands that print the results of the analysis operations on the EMG files.

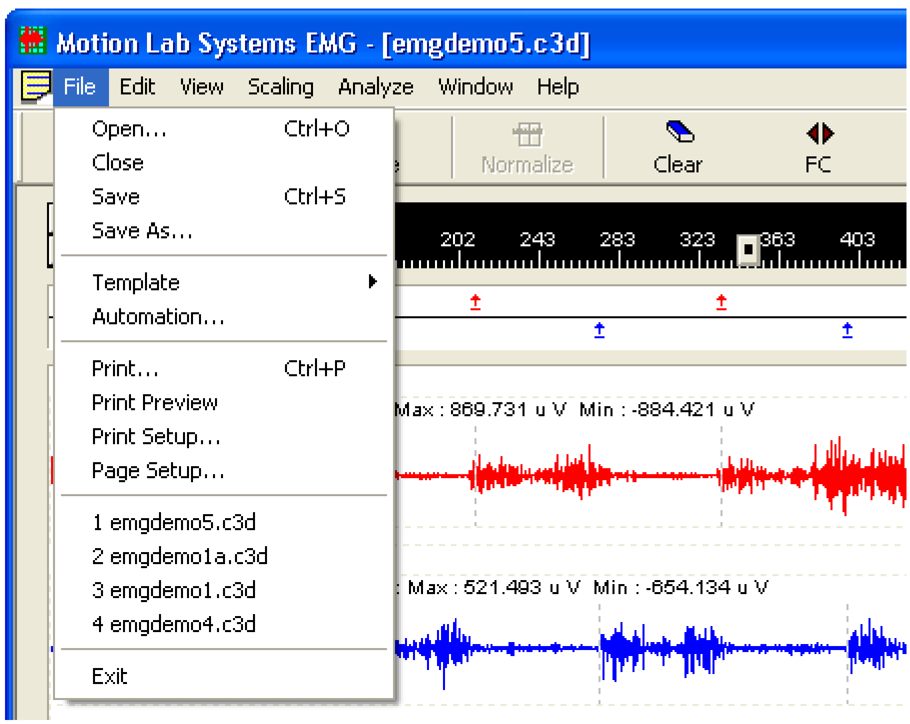


Figure 35 - The File menu opens, closes saves, and prints EMG data files.

A list of recently opened files is always displayed at the bottom of the *File Menu* so that you can rapidly access any of the most recently accessed files.

Open

The *Open* command is used to open a raw EMG data file. This file may contain data collected on any EMG system, provided that the data is in a format that the EMG analysis and graphing program recognizes. It is not required that you collect data from an EMG system manufactured by Motion Lab Systems in order to use this program if you have purchased either the ***EMG Analysis*** or ***EMG Graphing*** programs.

If you are using the ***Evaluation version*** of the program then you will only be able to open "watermarked" C3D files that are supplied with the EMG Analysis and Graphing programs. A warning message will be displayed if you try to open other files that have not been watermarked.

The *Open* command opens up a standard windows *File Open* dialog box and allows the electromyographer to browse through the directories and select the correct file by simply double-clicking on the filename.

The file types that are supported are:

- *.ADC Files (Oxford Metrics RSX and VMS systems)
- *.C3D Files (Biomechanics standard file specification)
- *.EMG Files (BTS TeleEMG systems)
- *.WDQ Files (Dataq CODAS data acquisition systems)
- *.ANA Files (Motion Analysis Corporation)

All non-C3D data files that are opened by this application are converted to the C3D file type whenever the data is saved – the original file is preserved without alteration. You can save the new C3D file using the *Save* or *Save As* commands.

Recent changes in the format of Vicon VAD files has resulted in Motion Lab Systems removing support for these formats in the EMG Analysis and EMG graphing applications.

If the original data file was not a C3D file then you will be prompted for a new file name when the data is saved to disk using the C3D format – the new C3D file will contain all of the original analog data, together with other parameters such as frame and sample rate, that are necessary to interpret the data. Other information, such as channel labels, descriptions, gain and channel assignments etc., can be applied to the C3D file via templates, which record configuration information that can be applied to groups of files automatically.

EMG data files can also be opened by dropping them into the EMG workspace, or by selecting the *"Open with EMG Analysis"* option from the right click menu in the Windows Explorer. This later operation requires that the required file type is associated with the EMG in the system registry, which is normally set up when the ***EMG Analysis*** or ***EMG Graphing*** applications are installed.

The program stores the names of the most recently opened files and displays them at the bottom of the *File* menu. You can open these files quickly by just clicking on their name in the menu. You can control the number of files to be displayed in this menu from within the *View:Defaults* menu. You can open multiple EMG data files simultaneously – the maximum number of files that can be opened at one time is only limited by the amount of memory available on your computer system.

Close

An open data file can be closed using this command, which closes all the windows containing the active file. If you have performed any operation that has changed the contents of the current file, then you will be prompted to save changes before you close the file. If you close a file without saving it then you will lose all changes made

to the file since the last time you saved it. You can also close an EMG data file by using the *Close* icon.

Save

This command can be used to save a modified EMG data file. This command saves the file using its current name and directory. The file will overwrite the original copy of the file that you opened initially.

If you want to change the name and directory of an existing file before you save it, to preserve the original data, choose the *Save As* command from the File menu.

If the currently open file is not a C3D files (for instance you have opened a WDQ file containing data from a Dataq CODAS system) and this is the first time that the file has been saved then you will be prompted to save the data to a C3D file.

If you have been working on a C3D file that is set to be *read-only* then the *Save As* dialog will be displayed, allowing you to select a new file name.

Save As

This command can be used to save a file to a new name or location and usually used when you wish to save a copy of the original file while keeping the original data unchanged.

When you use the command, the original file will be closed without any modification – all the changes will be saved to the new filename (using the C3D file format) that you specify – this new file will then be the current open file.

The Save As function can overwrite read-only files although you will have to confirm that you want to do this before the file is replaced.

You will be warned if the filename that you choose already exists and you will be asked if you want to overwrite the file – if you answer *Yes* then the data will be saved to the specified filename, overwriting the original file. If the filename already exists but is *read-only* and you answer *Yes* to overwrite the file then you will be warned that the file is read-only and asked again if you want to overwrite it. If you answer *Yes* then the *read-only* <u>will</u> be overwritten. By this point you will have been warned twice that the file both already exists *and* is red-only.

Templates

The Template feature of the ***EMG Analysis*** and ***EMG Graphing*** applications allows the electromyographer to automatically apply a previously saved "template" of labels, descriptions and channel assignments to the current EMG data file. Templates completely replace the "sessions" feature in the previous version of the software.

Templates are particularly useful when opening files (e.g., .ADC and .EMG files) that do not contain standard EMG channel names and descriptions.

Templates are very useful when you have a one or more standard EMG protocols that you want to use with a number of EMG data files. The template allows you to create a file that contains all the common information that you want to apply to each of the EMG data files that you open. Applying a single template to a number of EMG data files ensures that multiple datasets from a single session are all treated consistently with identical labels, descriptions, and channel selections etc.

The template file records the following information so that it can be applied as parameters within the C3D file header so that any other application can read and interpret the EMG data in a consistent manner.

ANALOG: LABELS – these labels allow software applications to reference each of the analog channels individually.

ANALOG: DESCRIPTIONS – these descriptions are used to assign standard muscle names or other descriptive references to each EMG channel.

EMG: TYPE – this parameter records the type of data (EMG, Foot Switches, Force Plate etc.,) that is stored in each of the analog channels. The EMG application only processes data from channels that are described as “EMG” channels.

EMG: SIDE – when the EMG application is used with gait related data, it is useful to keep track of the subjects’ side (left or right) from which the data was collected.

EMG: SEL – a typical analog data file usually contains analog data from non-EMG sources such as force plates and foot switches etc. Although useful, this information is not usually displayed when EMG data is presented for analysis so the “selection” parameter is used to control which analog channels are displayed by the ***EMG Analysis*** and ***EMG Graphing*** applications.

EMG: GAIN – EMG data is usually amplified before it is recorded. As a result the recorded signal levels are usually much higher then the levels recorded at the patient/electrode interface. The GAIN parameter allows the ***EMG Analysis*** and ***EMG Graphing*** applications to report the EMG signal levels as sensor levels – typically in microvolts (uV) or millivolts (mV) at skin surface.

EMG: GRF_TITLES: and **EMG: GRF_DESCRIPTIONS** – allow the electromyographer to customize each of the titles used to report the results of the ***EMG Analysis*** and ***EMG Graphing*** report pages.

Templates are very easy to use and allow electromyographers to quickly apply a complete environmental description to data files as each file is opened. The Template command has two simple options:

Create Template

The Create Template command opens a *“Save Template As”* dialog, which prompts the electromyographer to enter a filename to save the configuration information from the current file as a “template” to apply to other EMG data files. If you choose an existing template name then the current information will replace the original file. Template information is, by default, saved in a common directory which, by default is *C:\Program Files\Motion Lab Systems\EMGanalysis\templates*.

You can create an unlimited number of template files and, if desired, apply specific files to C3D file as they are opened for the first time using the *Automation* feature.

Apply Template

The Apply Template command presents an “Open” dialog, which allows the electromyographer to select an existing template file to apply to the current EMG data file. This will overwrite the parameters in the current file that control the label, description, channel type, side and selection information.

Working with Templates

Templates are very useful when you have a number of EMG data files that contain a series of trials that all use the same muscle protocol. The electromyographer can set up the first trial by applying the correct EMG descriptions, and channel assignments and then save this configuration as a template. Subsequent files can have these assignments made automatically by applying the template after the file has been opened.

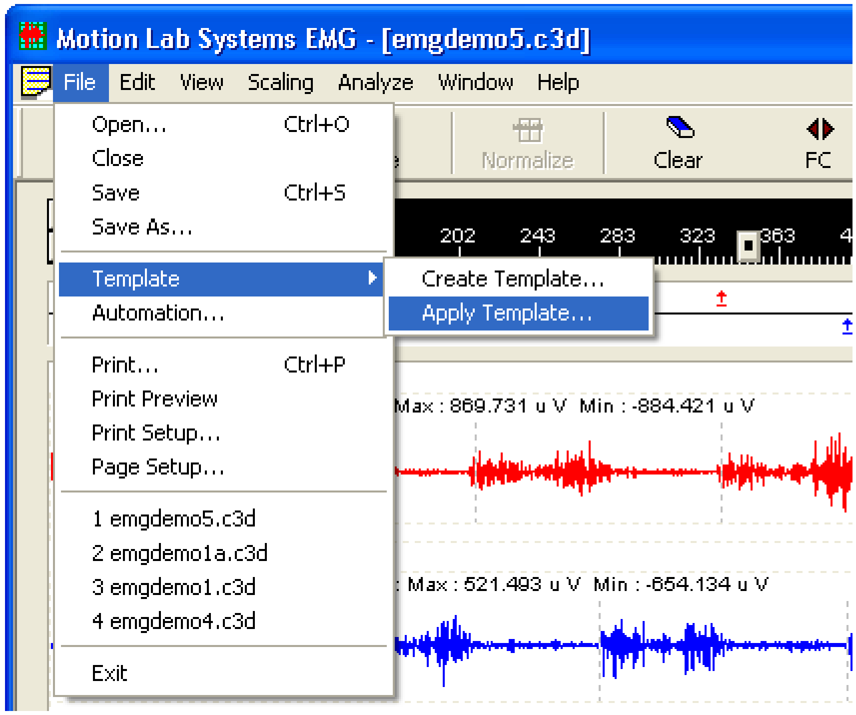


Figure 36 - Templates can be applied to any C3D file to quickly identify the data.

A template can be used to automatically calibrate all of the EMG data files in a single recording session.

The template feature can also be used to apply a common calibration or MVIC normalization to a number of EMG data files. If a separate EMG calibration record has been recorded (usually a sine wave of known amplitude applied to all the EMG inputs simultaneously) then this recording can be used to calibrate all of the EMG channels via the template. The procedure is simple, open the first EMG data file and use the "Scaling : By Calibration File" menu bar option to open the data file containing the calibration recording and simply click "Apply" after checking that the displayed calibration information is correct. The ***EMG Analysis*** or ***EMG Graphing*** application will then calculate the correct gain settings for each EMG channel and apply them to the current EMG data. Since these gain settings are calculated from the calibration file, and saved when a template is created, applying the template to other EMG data files in the session will result in their automatic calibration.

The same template feature can also be used when working with Maximum Voluntary Isometric Contraction (MVIC) datasets and can make normalizing with MVIC recordings relatively easy. MVIC normalization requires that a separate "maximal effort" recording exists for each muscle that is subsequently tested in a session. This MVIC recording is then processed and used to scale the EMG data so that each EMG channel can be described in terms of "percentage of MVIC". As each MVIC recording has to be applied individually to scale each EMG data channel this can involve a lot of work for the electomyographer and offers many opportunities for error.

Templates can be used to apply MVIC normalization to all of the EMG data files in a single recording session.

However, MVIC normalization using a template is relatively simple and works muck like the common calibration procedure above. Simply open the first EMG data file and, using the "Scaling : Normalization" menu, associate the MVIC recordings with their EMG channels and click "Normalize" to apply the MVIC normalization to the file. Then create a template and apply this template automatically to the rest of the files in this session – each file will then be normalized as soon as the template is applied. This saves a considerable amount of time as the calculation of the normalization values need only be performed once and, in addition, ensures that all

of the EMG data files are normalized in exactly the same way.

Templates can be applied automatically when an EMG data file is opened. This feature is enabled using the Automation feature in the ***EMG Analysis*** and ***EMG Graphing*** applications and selecting the appropriate template file to be applied to the EMG data whenever a file is opened.

Automation

The automation feature of the ***EMG Analysis*** and ***EMG Graphing*** applications allows the electromyographer to select one or more operations to perform on the EMG data file when it is first opened. These operations will be performed automatically, starting at the top of the list, if the check box is selected when any EMG data file is opened. This feature can save a considerable amount of time when analyzing multiple trials of EMG data as much of the laborious preprocessing of the EMG data can be performed automatically as the file is opened. This has the added advantage of ensuring that all EMG data is treated consistently by removing any doubts that differences between two data sets might be due to an inadvertent data processing error or omission.

The ability to automate the application of EMG descriptions, labels and channel selections offers substantial time savings when working with non-C3D data files.

Electromyographers can also select automation options at any time after an EMG data file has been created and apply them to the currently open file by choosing to either run all of the selected options, one after another, or individually.

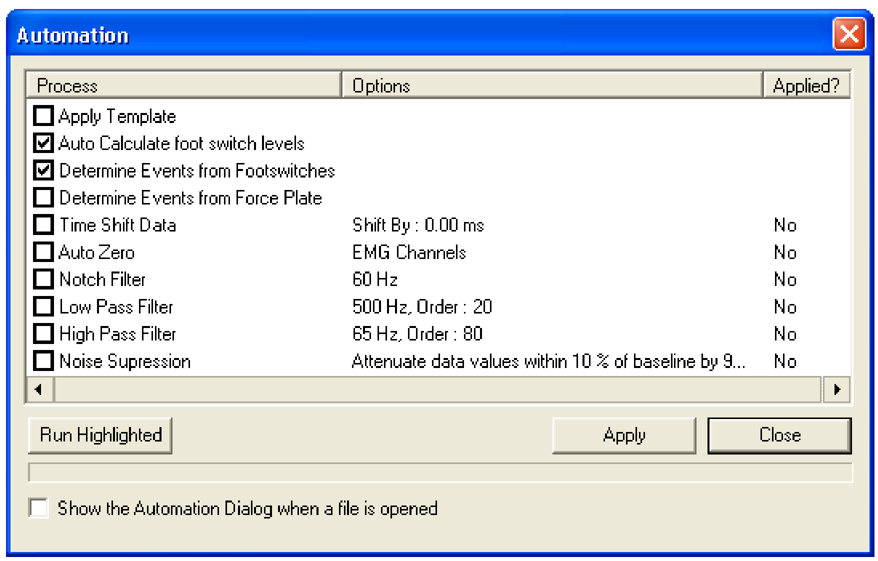


Figure 37 - The automation menu selects operations that can be applied as files are opened.

Apply Template

A template that contains EMG channel descriptions, labels and channel assignments, will be applied to the EMG data file as soon as it is opened. The electromyographer may select any one of a number of pre-existing templates, which will automatically apply channel selections and descriptions to the data file before it is displayed. Templates are created from existing EMG data files using the *File:Template* command described above.

Auto Calculate foot switch levels

Checking this box will automatically analyze the file for gait events when a file is opened. The ***EMG Analysis*** and ***EMG Graphing*** software tries to find gait events in the following order:

- If the open file is a C3D file then events will be read from either the EVENT:TIMES parameter or from the events stored in the C3D file header.
- From analysis of force plate data.
- From the foot switch channels present in the data file.

Determine Events from Footswitches

This automation command can automatically create events using any foot switch data that may be present in the data file.

You can adjust the levels at which the ON and OFF transitions take place using the *Events: Foot Switch Levels* command on the *Edit* menu.

For this command to work, it is essential that there is one channel that has been marked as foot switch channel on each side. This can be done using the *Apply Template* automation function.

Determine Events from Force Plate

Force plate data in a C3D file can be analyzed to determine the instants of foot contact the cycles of data present if 3D marker data is collected for markers around the foot. The ***EMG Analysis*** and ***EMG Graphing*** software gets information about the FZ (n) channels from the FORCE_PLATFORM: CHANNELS parameter and the number of force plates from the FORCE_PLATFORM:USED parameter and expects ANKLE and TOE markers need to be present.

When this method is used, sometime the ANKLE or TOE markers could be just at the edge of the force plates. You can choose to artificially extend the edges of the force plate by a few millimeters. This can be done from the *Channel Options* property page that can be accessed using the *Defaults* command on the *View* menu.

Time Shift Data

Almost all EMG data collection systems have measurable delays in the signal processing – especially if any filtering is implemented within the EMG signal processing. This option allows any known delay in the EMG data to be removed by specifying the amount of the delay in this option.

When this option is selected with a non-zero delay, the EMG data channels will be shifted backwards in time by the amount specified – so if a delay of 15ms is entered then this function will shift all the EMG channels by 15ms to remove the delay introduced by the data collection hardware.

This option is disabled by default and should be enabled with caution, taking great care to ensure that the correct delay is being applied to the data. While you can check with your EMG system manufacturer to obtain the delay values for each filter settings supported by your hardware, it is recommended that you determine or verify these delay values in the specific equipment configuration that you use to collect the data if this feature is important to your research.

Auto Zero EMG data

Recorded EMG data may contain small DC offsets due to the ADC configuration, data recording software, and/or the EMG hardware used to record the signal. This option will automatically remove any DC offset in the EMG data. This operation is only performed on analog channels that contain EMG data – the ***EMG Analysis*** and ***EMG Graphing*** applications calculate the optimum baseline level by calculating the average EMG signal level over the length of the trial and then using this information to adjust the recording EMG signal to produce an overall baseline level of zero.

Notch Filter

Under some circumstances the recorded EMG data may contain AC line noise that can almost completely obscure the EMG signal. Since this interference is usually a single frequency it is quite easy in most cases to remove the interfering signal with a notch filter at the AC line frequency. Both the ***EMG Analysis*** and ***EMG Graphing*** applications include a tunable notch filter than can be set to your countries AC line frequency – either 50Hz or 60Hz, set by double clicking on the notch filter description in the Automation dialog box.

The notch filter includes the ability to (optionally) remove harmonics of the AC line frequency. The harmonics option should only be used if the default notch filter is ineffective due to the presence of AC line harmonics.

Low Pass Filter

This feature allows the electromyographer to filter the EMG data to remove signal components above a selected frequency – both the frequency and the degree of filtering (filter quality or Q) can be preset. Typically this is used to remove unwanted *high frequency noise* (often from external sources or the internal noise inherent in many older analog EMG systems).

The filters values selected are applied to all of the EMG channels in the file – it is not possible to apply different filters to individual channels.

High Pass Filter

This feature allows the electromyographer to filter the EMG data to remove signal components below a selected frequency – both the frequency and the degree of filtering (filter quality or Q) can be preset. Typically this is used to remove unwanted *low frequency noise* (either motion artifact or AC line noise) that may be present in the EMG data signal.

The filters values selected are applied to all of the EMG channels in the file – it is not possible to apply different filters to individual channels.

Noise Suppression

When selected, this feature applies a noise reduction algorithm to the EMG data that can substantially improve the appearance of the EMG data by removing low level background noise from the EMG signal while leaving the EMG activity bursts unchanged.

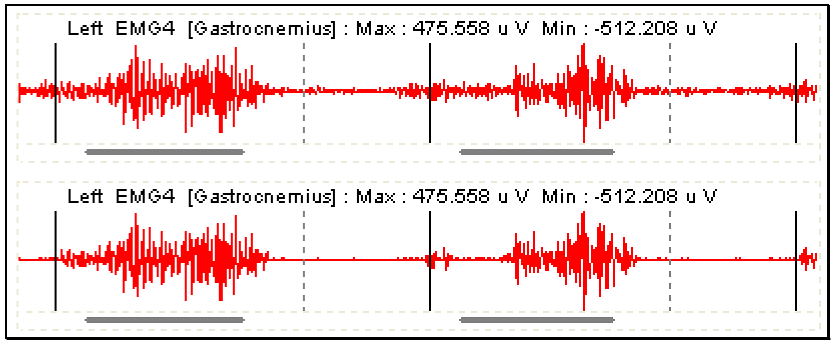


Figure 38 - Noise Suppression (lower trace) can clean up the EMG signal.

The noise suppression function works by calculating the average value of the full wave rectified EMG signal and then attenuating the raw EMG signal by a graduated amount if the calculated vales is below the selected threshold level. Typically, attenuating the EMG signal by 70-90% if the EMG signal is below 80% of the average value produces an EMG signal with a cleaner baseline and well-defined EMG activity bursts. The attenuation method used does not affect the timing of the EMG signal at all because the actual displayed data is always the original raw EMG signal with the amplitude dynamically attenuated.

Print

The ***EMG Analysis*** and ***EMG Graphing*** applications allow you to print the contents any of the analog channels in the data file as displayed in the main trial view. This command opens the *Print Channels* dialog box which displays the channel labels, allowing the electromyographer to choose the channels to print.

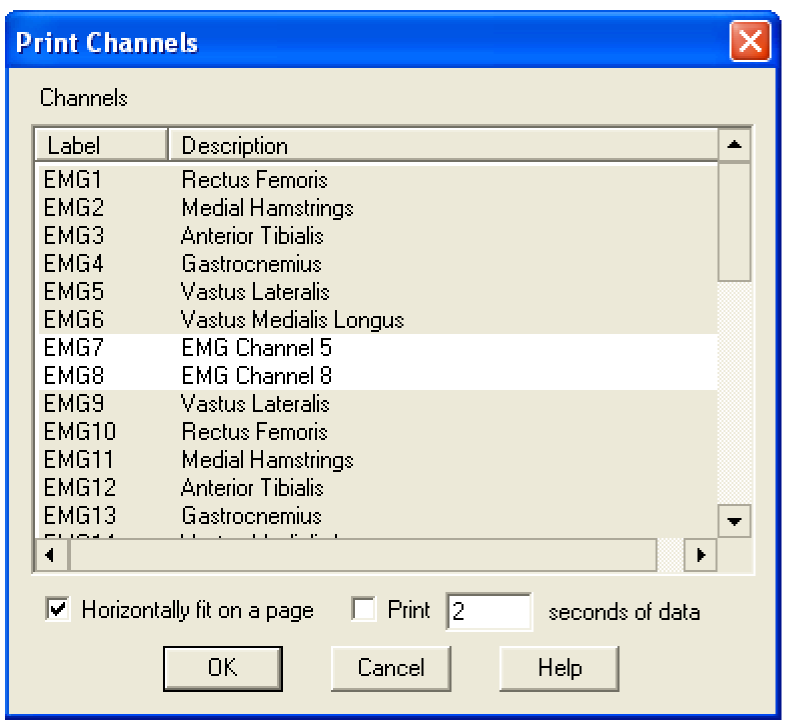


Figure 39: Print Channels dialog box

The *Print* dialog box will open with the currently selected EMG channels highlighted – these are the channels that will be printed by default. The default selection can be changed to add addition channels (via the mouse using control-click), or select a new range of channels. Any analog channel can be selected for printing regardless of its contents, allowing force plate information etc., to be graphed together with the EMG data if desired.

The *Print Channels* dialog box is displayed for both the print and print-preview functions. It offers the following controls:

Channels **-** this is a list box, which allows the electromyographer to scroll through all the analog channels in the file, displayed in the order in which they occur in the original analog data file. Initially, the selected EMG channels will be highlighted for printing but you can change this by selecting a new range or modifying list via control-click to add or remove channels from the list to be printed or previewed.

Horizontally fit on a page **–** when this box is checked, the data will be compressed to fit (horizontally) across a single page.

The actual number of pages printed will depend on the number of channels that have been selected, and on the number of analog frames in the data file. The vertical size of each plot will be the same as that on the screen and that can be set from the *Graph Defaults* page.

Print *n* **seconds of data** – select this option and enter a number of seconds to display. The printed output will consist of the first *n* seconds of data.

Print Preview

The application allows you to preview the analog channels in the data file. This command opens the *Print Channels* dialog box which allows you to choose the channels you want to preview. Once the channels have been selected, the electromyographer will be shown a preview of the current print output.

Print Setup

This command allows you to select a printer and a printer connection. This command presents the standard windows *Print Setup* dialog box allowing you to specify any available and select paper type, print quality etc. The actual options available vary with the selected printer and may be restricted by your system administrator.

Page Setup

This command allows you to set up the page margins. It presents you with the default windows *Page Setup* dialog box, allowing the electromyographer to choose the paper orientation and margins.

Most Recently Used file

This shows you a list of the most recently used files. You can control the number of files that will be displayed here using the *View:Defaults* command from the *General Page*. If you try to open a file from this list that does not exists or one that has been renamed then the filename will be removed from this list when the open operation fails.

Exit

Use this command to end your ***EMG Analysis*** or ***EMG Graphing*** session. If any changes have been made to the contents of any open files that you will be prompted to save the affected files.

The Edit menu

The edit menu has commands that can be used to edit the normal EMG data (used to display activity bars throughout the application), graph titles, analog channel information, gait cycles, and event information. In addition, if you have a copy of the Motion Lab Systems ***ReportGenerator*** application, then you can automatically start this application from the current ***EMG Analysis*** or ***EMG Graphing*** session

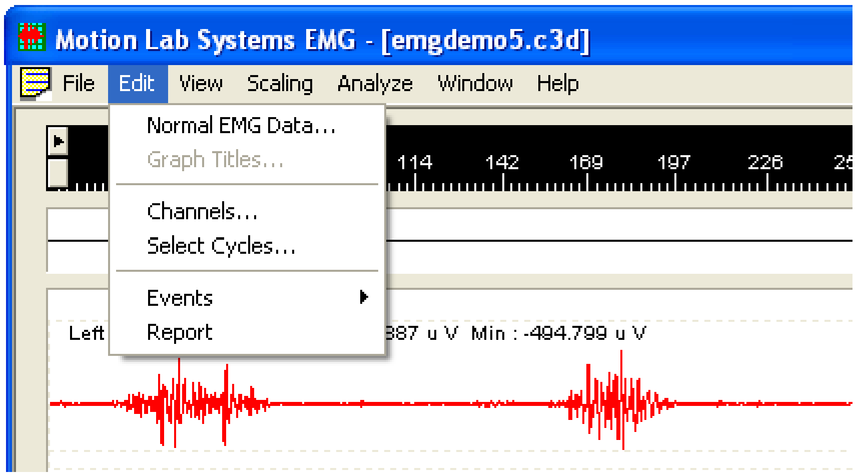


Figure 40 - The Edit menu

Normal EMG Data

A common question when reviewing EMG data reports is, "Is this activity normal?" In the case of EMG data recorded from a walking subject, one way of answering this question is to compare the recorded EMG activity from the subject, to the activity of other known normal subjects. The ***EMG Analysis*** and ***EMG Graphing*** applications come with a "normal activity database" that contains several different collections (or sections) of normal activity timings – all of which can be easily modified if desired to create custom EMG activity databases if your motion or gait lab has specific gait timing requirements.

The **Normal EMG Data** command allows the electromyographer to select one of several EMG Activity timing sections supplied with the ***EMG Analysis*** and ***EMG Graphing*** applications. Each section of the database is fully customizable and features specific collections of normal human gait timings collected from published literature or supplied by electromyographers. Details and sources for the normal adult EMG activity are listed at the end of this manual.

Note that the precise muscle activity timings vary between different normal sections depending on the source of the original data. Both of the commercial lists included use the specific muscle names and capitalization of the original sources and are only included for the convenience of clinicians using these manufacturers software.

Motion Lab Systems, Inc., makes no representation that the Normal Data profiles included with the software are accurate or representative. It is the end-users responsibility to verify that the normal data used is representative of the activity and expectations of the clinicians and researchers.

Normal Activity profiles for children aged one through seven years old are drawn from published data.

In addition to the adult EMG activity sections of the database, the ***EMG Analysis*** and ***EMG Graphing*** applications are supplied with age-related EMG timing information for children from one to seven years old. Two addition sections are supplied (*Upper Limb* and *Muscle Names*) that do not contain any timing information – these are provided for use in non-gait and upper limb analysis.

By default, all of the timing information is stored in a single file called muscle.ini, which can be edited manually if desired, although the easiest way of adding new muscle activity information is to use the graphical editor built into the ***EMG Analysis*** and ***EMG Graphing*** applications. The name of the default muscle database file can be changed in the *General Defaults*.

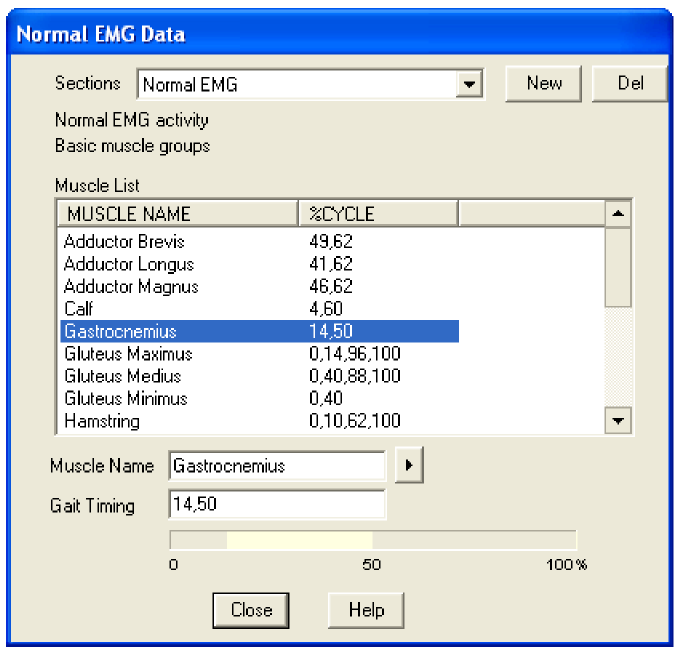


Figure 41: The normal EMG database dialog box

The graphical EMG database editor displays the section of the database and allows the electromyographer to scroll through the muscle names and associated timings, together with two lines of comments that help you to identify the correct database section. You can add new sections, or delete existing sections from the database, or edit any existing section entry.

The muscle names displayed in each section are the muscle names that are will be used as the default descriptions for the EMG channels in the creation of templates or for channel identification in the channel properties. The muscle names used in the EMG data file must match the muscle names in the current database section in order that the correct normal activity bar can be drawn with each EMG data channel.

The dialog box that enables you to edit and create different Normal EMG Data sections has the following controls:

Sections

This is a drop down box that lists all the sections in the currently selected muscle activity database file. Each section can contain any number of muscle activity timing

record – selecting a section in this box causes all the muscle data present in that section to appear in the Muscle List control below the section selection box.

New – Click on this button to create a new muscle database section. The new section name that you choose should not be the same as any other in the database. The New button opens the New Section dialog box allowing you to enter the section name and also enter two comment lines that will be displayed whenever the section is selected.

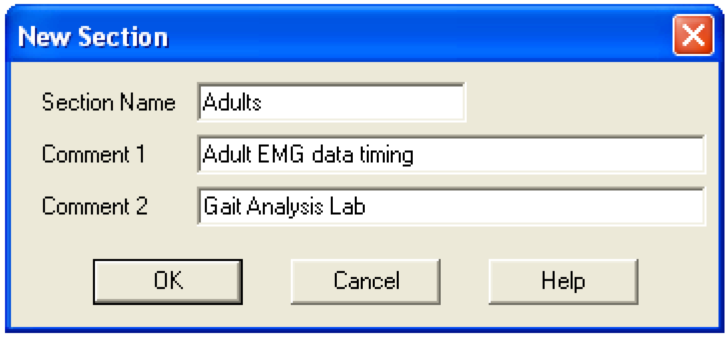


Figure 42: New Section dialog box

Note that each section in the muscle file can have two comments associated with it. These comments can be edited when the section is first created and cannot be easily changed subsequently. Comments are displayed below the section drop box and can be used to indicate the source of the EMG timing data.

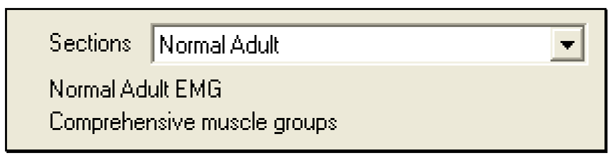


Figure 43 - Comments are displayed when each section is selected.

Del – Click on this button to delete the currently selected section, displayed in the section dialog box.

Muscle List

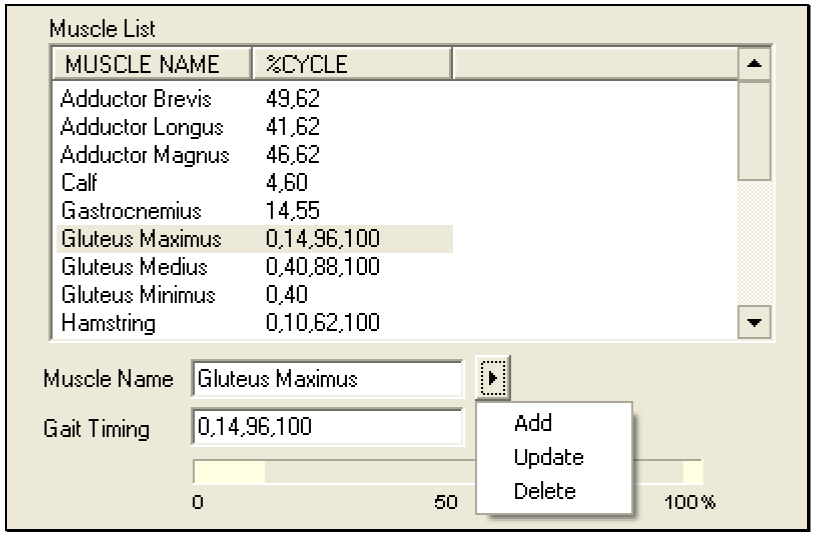
This is a list control, which has two columns. The first column shows you the name of the muscle while the second shows you the periods when the muscle is supposed to be ON. When an item is selected in this box, the *Muscle Name* and *Gait Timing* boxes displayed below the list will display the name and a graphical representation of the EMG activity.

Muscle Name

This is the name of the muscle.

Gait Timing

This is the gait timing of the selected muscle. All values should be between 0 and 100 and should be separated by commas. There should be an even number of values.



There are three things that can be done with the muscles in the dialog box:

Adding a muscle Timing

1. Enter the name of the muscle in the Muscle Name box.
2. Enter the periods when the muscle is ON in the Gait Timing box. These should be numbers between 0 and 100 separated by commas. There should always be an even number of entries with the first number indicating the percentage of the gait cycle that commences muscle activity while the second number indicates the percentage of the gait cycle where muscle activity ceases. There may be several periods of activity within a gait cycle. You can indicate that a muscle is active at the start of the gait cycle by using 0 as the first number, while using 100 as the last number would indicate that the muscle is active through the end of the gait cycle.
3. Then click on the button and choose the ***Add*** command. This action will add the muscle name and timing to the current section.

Deleting a muscle Timing

1. Choose the muscle you want to delete in the Muscle List box.
2. Click on the button and choose the ***Delete*** command.

Changing the muscle Timing

1. Change the muscle name in the *Muscle Name box*, or the ON/OFF periods in the *Gait Timing box*.
2. Click on the button and choose the ***Update*** command.

Graph Titles

This command is available to electromyographers who are using a registered version of either the ***EMG Analysis*** or ***EMG Graphing*** programs. It does not work with he evaluation version of the program. The *Graph Titles* command allows you to change the default titles that are displayed when the Analysis Graphs are viewed or printed out.

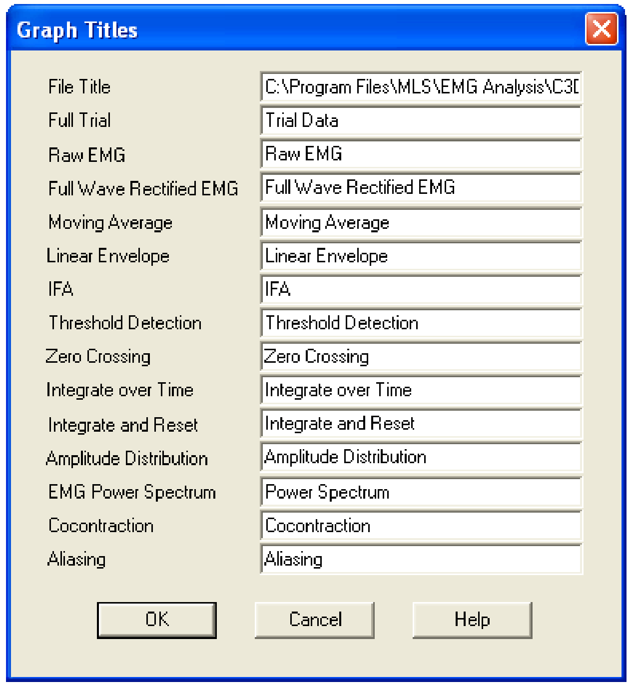


Figure 44: Graph Titles dialog

The titles entered in this dialog box are stored on the computer so that they will then be the default titles whenever a data file is opened – with one exception. The text entered into the *File Title* box is not saved on the computer but is instead written to the C3D file when the file is saved and stored in the C3D parameters.

By default, whenever the Graph Titles dialog is first opened for a file, this will be the location of the C3D file used to store the EMG data – unless some text has been previously entered.

You can store the subject ID in the file title – this information will then be written to the C3D file.

Thus, whatever text is entered here will be saved in the C3D file and printed out in the page footer whenever a graph is printed – if no text is entered then the file location information will be displayed on the printed report. Typical uses for this include storing a subject identifier, trial conditions or other relevant data as this information will then be stored within the file and displayed whenever the data is displayed or printed in the future.

Channels

This command can be used to edit some of the information that is associated with each analog channel. The items that can be changed are:

- Label
- Description
- Type
- Side
- Selection state
- The calibration data

This command opens the *Channels* dialog box where all the above information can be changed.

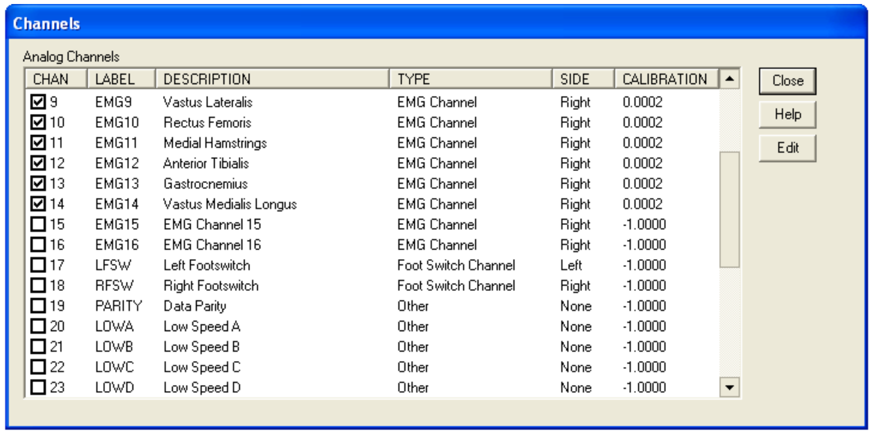


Figure 45: Channels dialog box

The *Channels* dialog displays the information about the analog data in six columns, each of which can be edited within this page.

Chan

This is the physical analog channel number starting from channel one. Each channel number has a check box to its left. If this box is checked, the channel is selected and will be displayed in the full trial view. Analog channels that are not checked here will remain in the C3D file but will be hidden from the user. Typically you will want to select the EMG channels and leave all non-EMG data hidden.

Label

This is the analog signal label associated with each channel – this may be referenced by software to identify or select specific analog data channels during data processing. You can double click on this value to edit it. The convention is to keep the analog channel label short (less than 16 characters) and to use only numbers (0-9) and upper case (A-Z) letters. See the C3D format user guide for a detailed discussion of the analog label parameter.

Description

This is the description string associated with each analog channel. Double clicking on this parameter will produce a list of muscle names, allowing the electromyographer to quickly select a muscle name form the current section within the Normal EMG database. Since these muscle names are stored within the database, this provides an easy method of associating a standard muscle name with each EMG channel and eliminates spelling mistakes and typos. Note that the Normal EMG database may have several lists (sections) of names so if the name that you wish to use is not found in the displayed list you may need to check your current Normal Database settings.

Type

This parameter reflects the type of data present in each of the analog channels. When you double click on this, a drop box allows you to assign a type to the channel. The available types are:

- EMG Channel – this tells the ***EMG Analysis*** and ***EMG Graphing*** applications that the channel contains EMG data and enables other functions within these programs to automatically select the EMG data for analysis or processing.

- Processed EMG – this indicates that the channel data has been created by the ***EMG Analysis*** and ***EMG Graphing*** applications as a result of an analysis operation.
- Force Plate Channel – this tells the ***EMG Analysis*** and ***EMG Graphing*** applications that the channel contains information collected from force plates. This information may be used with foot switches to detect or analyze gait event timing.
- Foot Switch Channel – this tells the ***EMG Analysis*** and ***EMG Graphing*** applications that the channel contains data collected from foot switches. This channel can then be used to detect gait events such as heel strike and toe-off, permitting gait cycle based analysis of the EMG data.
- Event Channel – this tells the ***EMG Analysis*** and ***EMG Graphing*** applications that the channel contains event information. This is a channel that is created by the ***EMG Analysis*** and ***EMG Graphing software*** to store event information.
- Other – any analog channel not included in above categories.

It is very important that each analog channel is identified correct in this display as certain analysis and display functions are only available for channels that are identified as EMG channels.

Side

This is the side (left or right) to which the analog channel belongs. You can select the appropriate side from the drop box when you double click on the side. It is important that you assign a side to the EMG channels.

Calibration

This is the individual calibration value for each analog channel and usually is either a negative value (typically –1), indicating that the channel is not calibrated, or else it contains a positive value that is used in combination with the C3D scaling calculations to calculate the exact gain used with each analog channel. Although this value may be editing here, it is strongly recommended that electromyographers change the calibration values using the dialogs provided within the ***EMG Analysis*** and ***EMG Graphing*** applications.

Editing the Channel data

If a single item has been selected in the list then you can edit the data in place by simply clicking on the item that you want to change. However, if you want to change the data affecting several channels – for instance to deselect all the force plate channels to prevent them being displayed and printed – then you can use the **Edit** button after selected either a range of analog channels (via click and shift-click or else using control-click to select individual items) and simply choose the appropriate command to select analog channel type, channel side or select/deselect channels for analysis and display from the menus displayed.

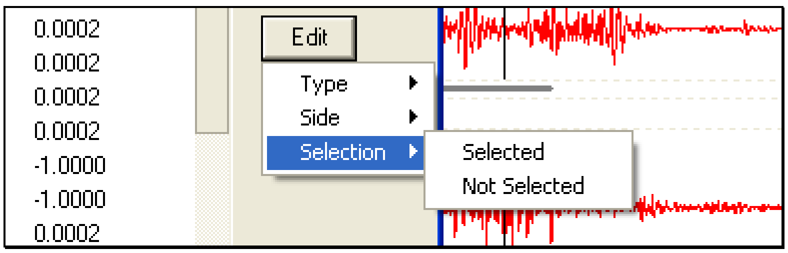


Figure 46 - most channel properties can be set via the click of a mouse.

Select Cycles

This command allows control of the gait cycles that are included when analysis operations are performed – it is generally used to exclude certain cycles from processing. This is especially useful when you want to exclude cycles at the beginning and end of a gait analysis trial from being added to the ensemble average in the envelope processing.

The Select Cycles command opens a simple dialog box where you can choose the cycles you want to include or exclude – by default, all gait cycles are included. There are separate controls for gait cycles from each side, allowing individual cycles to be removed from analysis by clearing the check box. The frame numbers defining each gait cycle are displayed together with the length of each gait cycle to aid the electromyographer when selecting individual gait cycles.

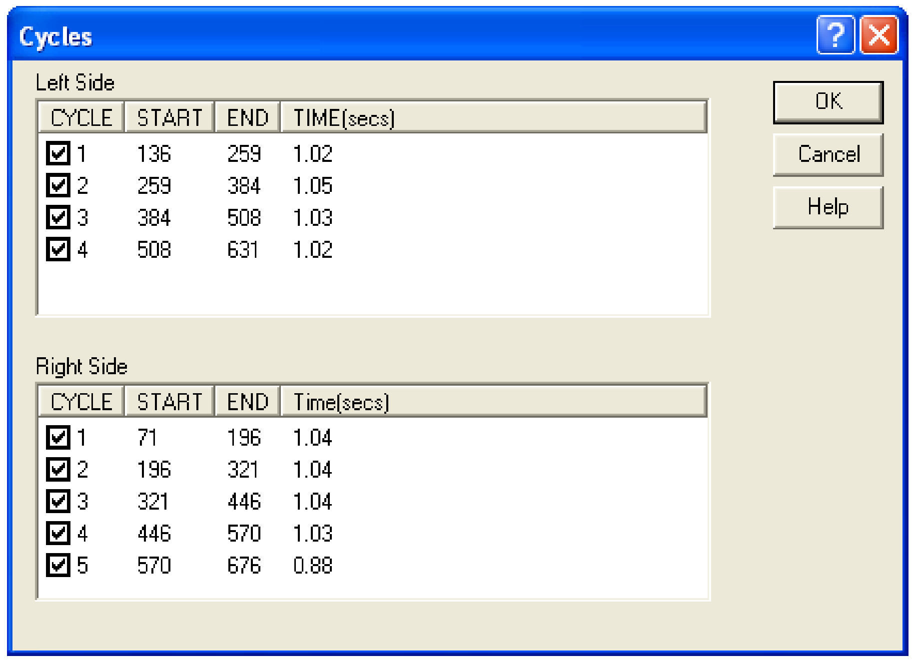


Figure 47: Select Cycles dialog box

Events

The Events menu controls offer a number of different methods of controlling the events that define the sections of the EMG channels that are analyzed whenever any analysis function is performed. Events can be displayed in the Full Trial view but do not affect any of the functions used to view the raw trial data. Events are only required when data is analyzed. When an EMG data file is opened, both the ***EMG Analysis*** and ***EMG Graphing*** applications will look for predefined events that are already recorded in the data file and will use this if possible. If no predefined events exist in the file then the ***EMG Analysis*** and ***EMG Graphing*** applications will search the file for any data that can be used to define and create gait events.

The ***EMG Analysis*** and ***EMG Graphing*** applications define two types of event for use in gait analysis – these are Foot-Contact and Toe-Off. In any trial of EMG data, the first Foot-Contact event defines the start of the EMG period that will be analyzed, and the second Foot-Contact (on the same side) defines the end of the EMG analysis period. The Toe-Off event is used to define the stance and swing periods within each gait cycle. Foot-Contact events are only analyzed in pairs (a single Foot-Contact does not define a gait cycle or EMG analysis period), while Toe-

Off events must always occur within a pair of Foot-Contact events on the same side. Toe-Off events are not required in order to analyze a period of EMG signal.

Events are displayed in the event bar at the top of the trial window in both the ***EMG Analysis*** and ***EMG Graphing*** applications. The event bar displays left and right side events as miniature icons representing foot-contact and toe-off. The icon colors match the colors selected to identify the left and right side EMG signals – by default these are red and blue.

Both Foot Contact and Toe Off events may also be displayed in the trial view of the data as vertical lines across each EMG channel – a solid line denoting a gait cycle defining Foot Contact event, while a dotted line indicates a Toe Off event at the instant of transition from stance to swing in gait.

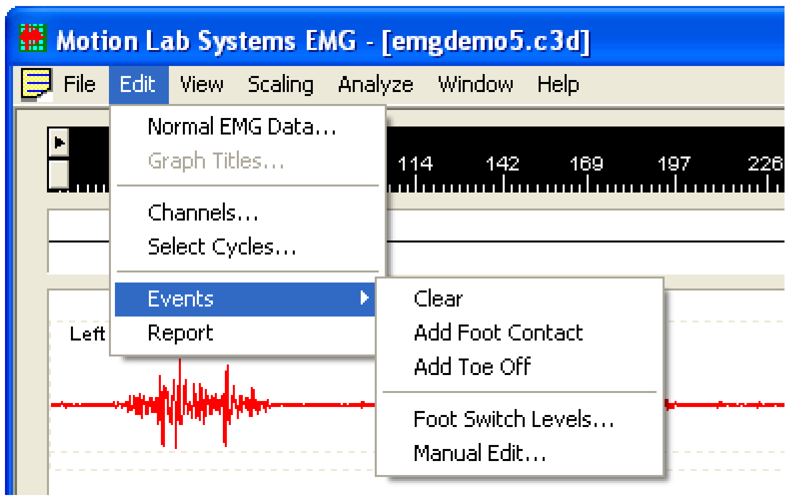


Figure 48 - The Events sub-menu offers complete control of event timing.

Event timing information is stored in the C3D file parameters using the EVENT parameter group – this information is compatible with the event information stored by Vicon Motion Systems applications. The Events menu provides a simple interface to edit or create events stored in this format – as a result, editing the events recognized by the ***EMG Analysis*** and ***EMG Graphing*** applications will automatically synchronize the stored C3D event information used by Vicon Motion Systems applications.

Events:Clear

This command can be used to clear all the gait events from either side – if you have events on both sides (left and right) then you must use the command twice to clear all of the events from a trial. This command is also available on the toolbar as the *Clear* command. The *Clear* command turns the cursor into an eraser allowing the electromyographer to click on the event bar side that is to be cleared of all events. A simple mouse right-click exits the *Clear* command. This command is available only when the whole trial is being viewed.

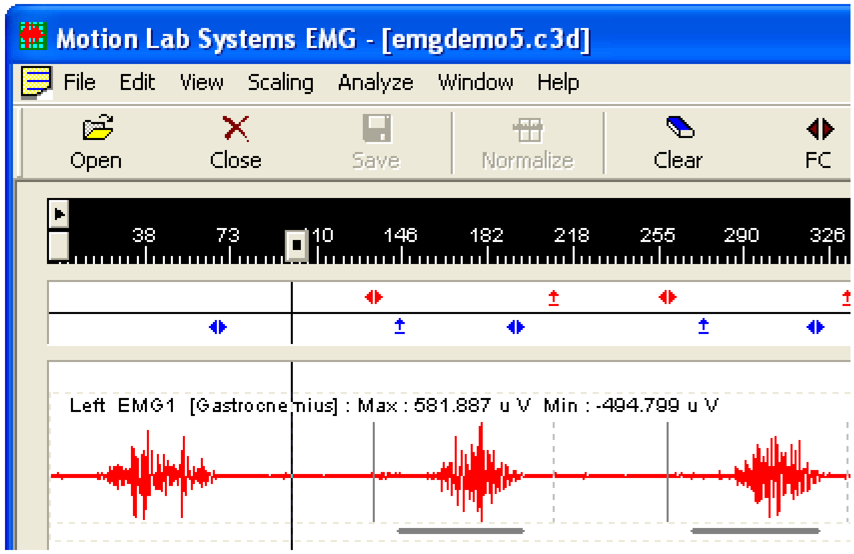


Figure 49: Event bar while viewing a trial

Events: Add Foot Contact

The "Add Foot Contact" command is fast and easy to use but is the least accurate event method.

This command can be used to manually add a foot contact event to the event bar and works in exactly the same way as the "FC" toolbar icon. The *Add Foot Contact* command turns the cursor into a miniature foot contact icon, allowing the electromyographer to click anywhere on the event toolbar to create a foot contact event.

When all the foot-contact events have been created, a simple right-click of the mouse cancels the command and returns the cursor to its normal style. This command is available only when the whole trial is being viewed.

Events: Add Toe Off

The "Add Toe Off" command is fast and easy to use but is the least accurate event method.

This command can be used to manually add a toe-off event to the event bar. It works in a similar manner to the *Add Foot Contact* command, briefly turning the cursor into a miniature toe-off icon, allowing the electromyographer to click inside the left side range or right side event bar areas to create a toe off event.

When all the toe-off events have been created, a simple right-click of the mouse cancels the command and returns the cursor to its' normal style. This command is available only when the whole trial is being viewed.

Events: Foot Switch Levels

Foot Switches provide one of the most convenient ways of recording gait events automatically and can be very accurate if the foot switches are placed on the subjects' feet correctly.

The ***EMG Analysis*** and ***EMG Graphing*** applications both include the ability to automatically detect gait events from foot switch signals that are recorded onto a channel of analog data. A foot switch recording typically consists of a pair of analog channels dedicated to recording left and right side switch closures from small contact switches placed on the patients' feet. These switch contacts are recorded as a series of analog voltages on each channel – each unique voltage level indicating a different combination of switch closures. Contact your EMG system manufacturer for additional details of the exact method used if your EMG hardware supports foot switches.

Although both the ***EMG Analysis*** and ***EMG Graphing*** applications will automatically attempt to discover the correct foot switch levels when an EMG data

file that contains foot switch channels is opened, the applications also provide the electromyographer with the ability to manually set the analog channel levels that define foot-contact and toe-off by using the *Events:Foot Switch Levels* command to set the analog levels that define the foot-contact and toe-off transitions. The command opens the *Foot Switch Levels* dialog box that allows each level to be set individually.

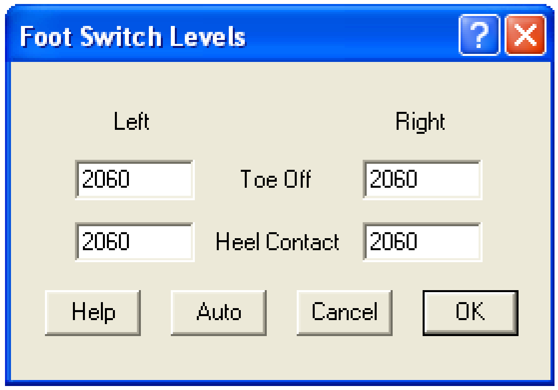


Figure 50: Foot Switch Levels dialog box

The values entered in the Foot Switch Levels dialog are the binary analog sample values for each side – two boxes are provided for the Foot Contact and Toe-Off levels:

- ***Toe Off*** **-** When the analog value on the foot switch channel goes from above this level to below it, a toe off event is said to have occurred for the selected side.
- ***Foot Contact*** **-** When the analog values on the foot switch channel goes from below this level to above it, a foot contact event is said to have occurred for the selected side.

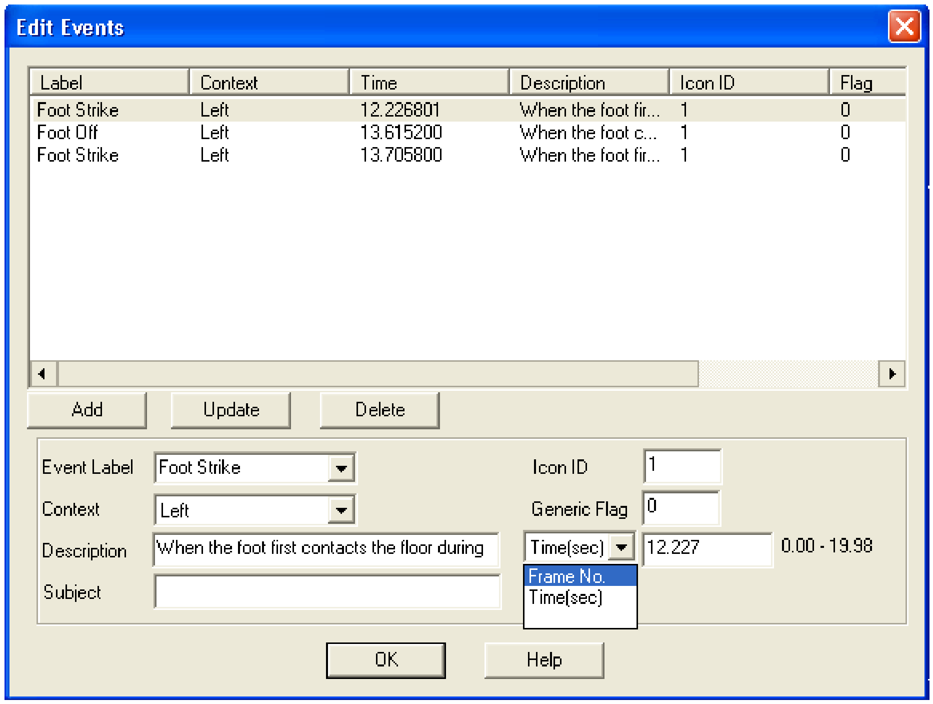
The Foot switch levels can be reset to the default levels at any time by clicking on the “Auto” button. Foot Switch levels can only be changed when the trial EMG data is displayed – this command is not available while data is being analyzed.

Events: Manual Edit

Manual entry of the event information is the most accurate method of entering event information.

In some cases electromyographers may wish to manually add events to a C3D file using a list of frame numbers that define a particular series of events. This command allows you to manually enter event information and is available only when you are viewing the trial data. This opens the *Event Edit* dialog box.

The *Edit Events* dialog displays a list of all the events that exist in the current file and shows the event label (generally Foot Strike of Foot Off), the context (usually Left or Right for gait events) and the time in seconds at which the event occurred. Selecting an item from this list will cause its associated values to be displayed in the *Event Label*, Context and *Time(sec)* boxes, where they may be edited if desired. Although the program records all events in terms of seconds from the start of data, the program also support events entered in terms of Video Frame Number for compatibility with older applications like Vicon Clinical Manager (VCM) that only support events at video frame boundaries.



An event is defined by entering all of the following information:

- ***Context* –** all events are associated with a context – for most gait related events this is expressed in terms of Left or Right but other activities may use different terms. This drop box allows you to choose the context to which the event belongs.
- ***Event Label*** – this drop box allows you to select either Foot-Strike or Foot-Off as the event type.
- ***Time(sec)*** – this allows you to enter the time in seconds at which the event occurs.
- ***Frame No*** – this allows you to enter the video frame of data as an alternative to entering events in seconds..

Once this information has been entered the electromyographer can click on the ***Add*** button to create a new event or the ***Update*** button to change the information for an existing event. Events can be deleted by selecting an event in the list and clicking on the ***Delete*** button.

Report

This command can be used to open the ***Report Generator*** – a separate application available from Motion Lab Systems, which can create a wide variety of detailed

reports beyond the simple graphical reports that the ***EMG Analysis*** and ***EMG Graphing*** applications can create.

In ***Report Generator***, the last used report format is the one selected by default. The last GCD file that was written to by this application is the one that is sent to the ***Report Generator*** application and is opened by that application. For this command to work the ***Report Generator*** application must be installed should have been run at least once.

View menu

The *View* menu controls all of the options that affect the appearance of the ***EMG Analysis*** and ***EMG Graphing*** applications, allowing the electromyographer to control the display attributes of the application (toolbar, status bar etc), the appearance of the displayed EMG data (raw, rectified etc.), the individual EMG channel properties, the EMG data analysis options (via the *Options* sub-menu), and also allows the electromyographer to configure many of the internal operations of the application and the colors used via the *Defaults* sub-menu.

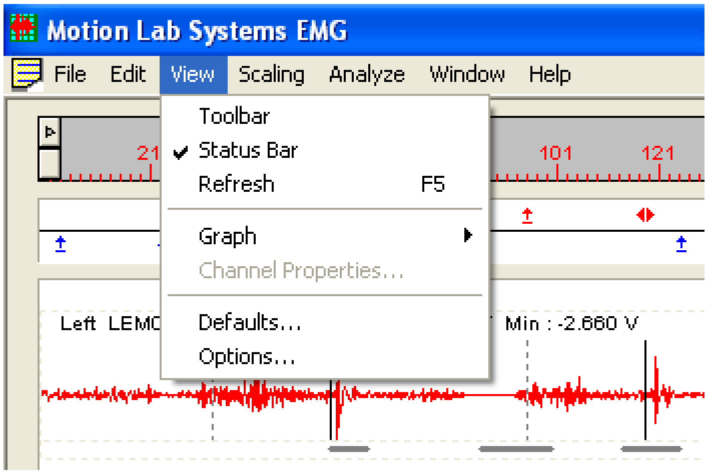


Figure 51 - The View menu controls the appearance and behavior of the application.

Toolbar

This menu item toggles the toolbar. If there is a check mark against the Toolbar then the tool bar will be visible, otherwise it will be hidden from view allowing more of the screen to be used to display EMG data. The buttons on the tool bar simply provide quick methods of accessing menu items to open, close and save files, edit gait events and print the data.

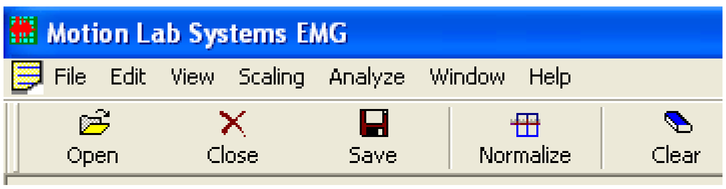


Figure 52 - The toolbar offers quick access to common functions.

Placing the mouse pointer over the button displays a tool-tip that tells you the command that will be executed by clicking on the button.

Status Bar

This command displays or hides the status bar at the bottom of the application window, which is used to display information about the application and the current EMG data file.

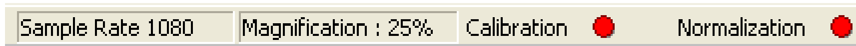


Figure 53 - The status bar displays information about the current EMG data file.

There are four informational panes in the status bar that display the current data sample rate in samples per second, an indication of the time compression in the current display, and the calibration/normalization status of the data.

The sample rate of the current data is shown to help the electromyographer estimate the potential bandwidth of the current data file.

The application will always open the data file and display the entire trial contents – this pane provides some indication of the degree to which the current view has been compressed.

The Calibration indicator shows the calibration status of the current data file – this indicator will be green if the EMG channels are calibrated and yellow if calibration information exists but has not been applied to the data file.

The Normalization status of the data can also be determined from the status bar – this indicator will be green if the data file has been normalized.

Refresh

The Refresh option will cause the ***EMG Analysis*** and ***EMG Graphing*** applications to redraw the displayed data on the screen – this is useful if the screen display becomes corrupted for any reason. Both the ***EMG Analysis*** and ***EMG Graphing*** applications update the screen using the installed operating system video drivers – if screen corruption is a continual problem then you may want to check that your computer is using that latest version of the video driver software or upgrade your video card. The Refresh option is also available at any time via the F5 function key.

Graph

The various Graph options in the view menu control the way that the EMG data is presented in the trial view. These options do not affect the display or processing of the analyzed data in the ***EMG Analysis*** and ***EMG Graphing*** applications – only the display of the current trial information is affected.

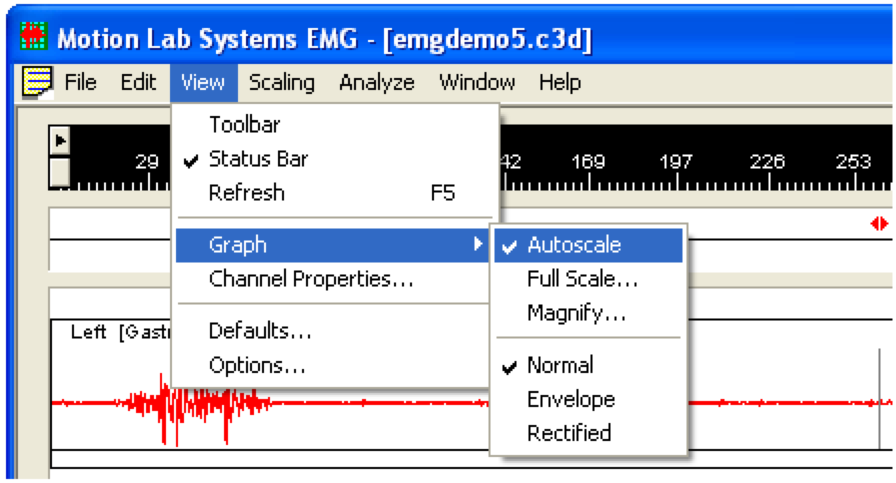


Figure 54 - The view menu offers several graph display options.

Note that although the various graph display options described here can be combined to offer a total of twelve unique views of the data, the illustrations that follow will use raw data to show the various scaling options and will auto scale the EMG data processing displays. The default display method for all full trial EMG data is to present auto scaled normal data.

The next three options are available for individual EMG channels, allowing the electromyographer to adjust the display scale for each channel individually. This means that these menu options will *only* appear if an individual EMG channel has been selected. These options are also available as Default settings where they are applied to all the displayed EMG channels rather than individual channels.

Autoscale

This menu option will be disabled unless an EMG channel has been selected.

This is the default method of displaying the trial data – the auto scale method simply normalizes the selected channel of EMG data to the maximum and minimum value of the data found within the selected channel.

This option normalizes the data display so that the entire range of the EMG data is displayed – when EMG data is auto scaled, each channel will appear to have the same visual size regardless of the actual magnitude of the data. The actual peak recorded magnitudes of the EMG signal will normally be displayed, together with the channel name etc, within each channel display area allowing the electromyographer to distinguish between channels that have radically different EMG signal levels.

Uncalibrated EMG channels that display Max and Min signal levels that match the recording system maximum and minimum levels can be assumed to contain at least some clipped EMG signals. EMG channels that display Max and Min signal levels that are less than the recording system limits must therefore have been cleanly recorded without any clipping.

This display method does not actually change the EMG data – the actual magnitudes of the different channel contents are preserved and can be displayed, together with the channel name, side and label in the trial view of the data.

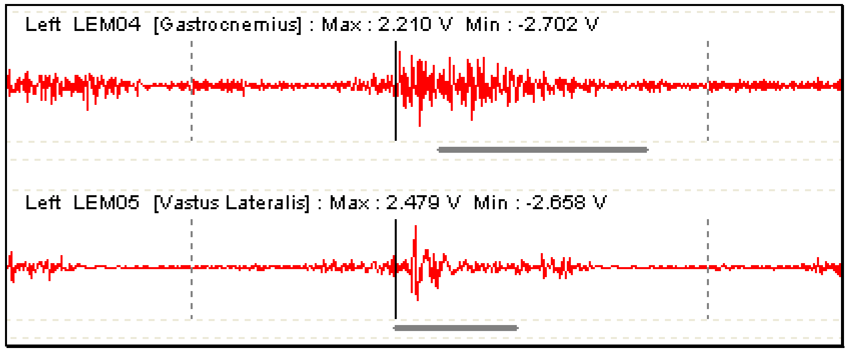


Figure 55 - The Auto scale display method normalizes all channels to 100%

Full Scale

This menu option will be disabled unless an individual EMG channel has been selected.

When individual channel data is displayed using the Full Scale method, the display will be scaled to the physical scale selected by the user. This option allows the user to scale individual channels to specific ranges ensuring that the displayed data will accurately represent the actual differences in recorded signal magnitude.

This display method requires that the data range and scaling information are both entered correctly. If the entered data range and scaling values are too small then the display will be clipped – if the values are too large then the EMG may appear to be too small to appear in the display. As a result, this option is generally used with un-calibrated EMG data – usually as an aid in determining the correct recording signal levels.

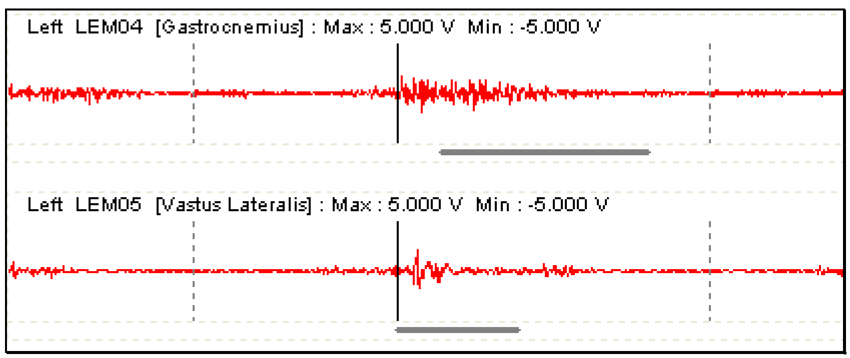


Figure 56 - The Full Scale display method displays the actual signal amplitude.

This display method does not actually change the EMG data – the actual magnitudes of the different channel contents are preserved and can be displayed, together with the channel name, side and label in the trial view of the data.

Magnify

This menu option will be disabled unless an individual EMG channel has been selected.

The Magnify command displays the Trial EMG data after applying a magnification factor of between 1 and 10. This view is sometimes useful when debugging EMG data recording problems or investigating individual EMG data quality but this is not a display method that has any real clinical or research use.

Note that in most cases, applying a magnification factor to normally recorded EMG data may cause the displayed data to clip – this occurs when the data becomes too large for the height of the display. As a result, the portions of the EMG data that lie outside the display area are "clipped" and are not visible. Since this command

applies a selected magnification factor to the displayed data, it is impossible to tell whether the recorded EMG signals are actually clipped from the data display.

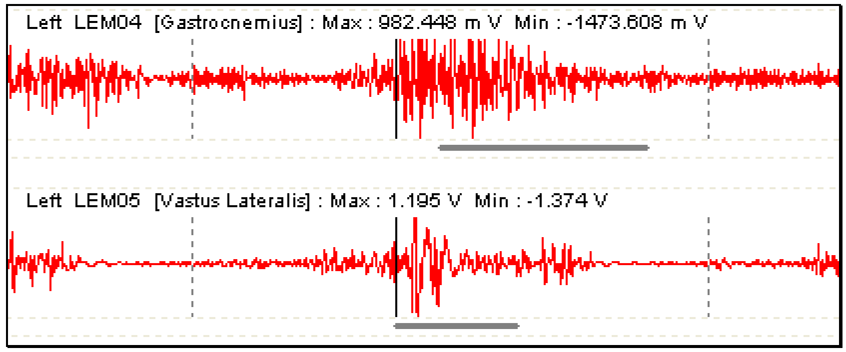


Figure 57 - The Magnify display option amplifies the EMG signal.

The Magnify display method, like the Full Scale and Auto scale methods, does not actually change the EMG data – the actual magnitudes of the different channel contents are preserved and can be displayed, together with the channel name, side and label in the trial view of the data.

Normal

This menu option applies to all displayed EMG channels.

The Normal EMG data display shows the raw EMG signal, together with optional channel information such as muscle names, channel labels and signal amplitude. This is the preferred method of viewing trial data as it allows the electromyographer to quickly assess the quality of the recorded data and identify channels that contain excessive artifact or are otherwise unsuitable for analysis.

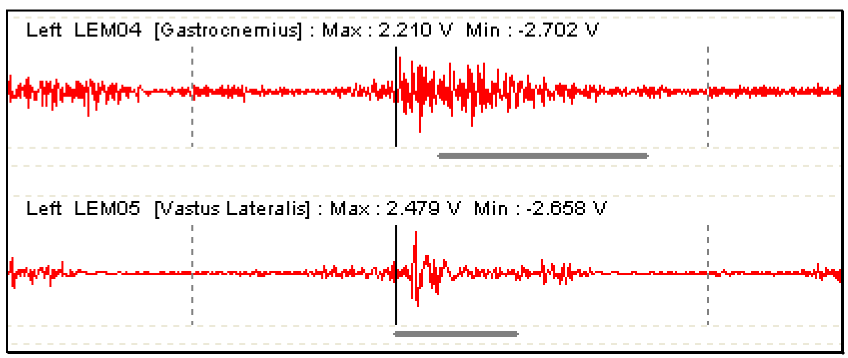


Figure 58 - The Normal full trial display shows the raw EMG data.

The Normal display method shows the actual data recorded, without any processing and can be printed to provide a record of the trial together with optional gait events. The solid vertical lines in these illustrations indicate foot contact, while the dotted vertical lines indicate toe off, allowing the electromyographer to identify the stance and swing phases of gait. The horizontal bars below the EMG data indicate the selected “normal activity” of each muscle, based on the current selection from the Normal Activity database.

Envelope

This menu option applies to all displayed EMG channels.

The envelope trial data display does not show the raw EMG data – instead the data is processed with a Linear Envelope Analysis to generate an “enveloped EMG” display of the trial data.

While this display method is sometimes preferred by clinicians as being considered easier to interpret, it is should not be used by default as the envelope processing removes a lot of useful information about the quality of the original EMG data.

The appearance of the full trial envelope display is controlled by the Linear Envelope Analysis options.

The envelope display is identical to the ***Linear Envelope analysis*** option, and is controlled by the same settings. This allows the electromyographer to control the envelope display of the full trial data by selecting the envelope cutoff frequency of the displayed data – in practice, envelope filter frequencies of 6 to 12Hz are common. Note that the signal amplitude of the envelope display will reflect the value of the processed envelope, not the amplitude of the original raw EMG data.

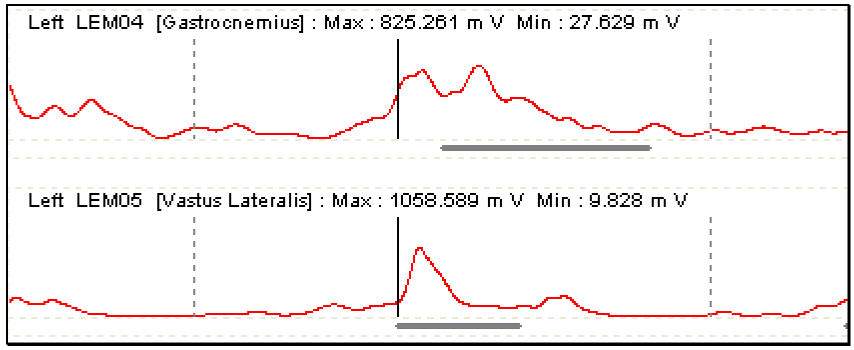


Figure 59 - Envelope display of the full EMG trial data.

The envelope display of the full trial data does not change the EMG data in the original file in any way. This display method can be printed to provide clinicians with a quick overview of all muscle activity together with gait timing.

Rectified

This menu option applies to all of the displayed EMG channels.

The rectified trial data display is sometimes preferred to the normal raw data display as this display method preserves almost all of the visual information in the original EMG data recording.

Since calculating the mathematical absolute value of the raw EMG signal generates the rectified EMG data display, the displayed signal amplitudes are different from those shown in the normal raw display. Rectified data does not contain any negative signal components, all data values are positive. As a result, the maximum signal amplitude will be the largest negative or positive value from the original raw signal, while the minimum value will be zero or very close to zero.

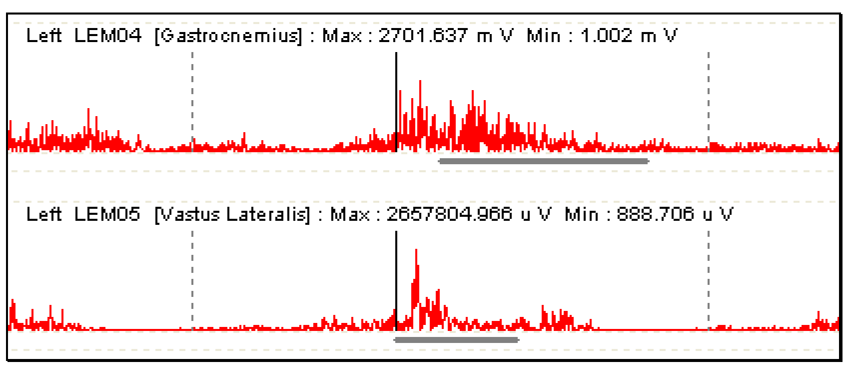


Figure 60 - The rectified display retains many of the characteristics of the raw data.

The rectified display method does not have any options and does not change the EMG data in the original file in any way. This type of display can be printed to

provide clinicians with a quick overview of all muscle activity together with gait timing.

Channel Properties

The ***EMG Analysis*** and ***EMG Graphing*** applications maintain control of the various properties every analog channel in the data file. The Channel Properties provides access to these attributes and allows them to be changed at any time. Channel Properties are only available when a single analog channel is selected – channels are selected by clicking on an individual channel plot, while the full trial is being viewed. This will cause the normally dotted lines, bounding the EMG channel plot, to become darker and solid – indicating that the channel properties will be displayed, and may be modified, for the selected channel.

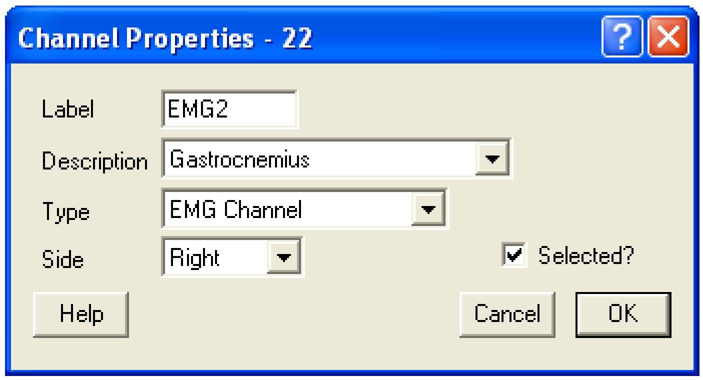


Figure 61: Channel Properties dialog box

The channel dialog box displays the physical analog channel number in the title bar while the analog label, description, type, and assigned side of the selected data channel are displayed, and can be edited within the main dialog.

Label – the channel label is usually assigned when the EMG data file is created and is usually used by software applications to identify each channel. Each label should be unique and may contain uppercase letters (A-Z) and numbers (0-9).

Description – the description is used to describe the contents of each channel and is usually used to record the muscle name associated with the channel. The description associated with each channel can be changed by selecting muscle names from the list presented in a drop list box. The names in the list are selected from those available in the currently selected section of the Normal Muscle Database.

Type – each channel has an assigned property that identifies the type data present in the channel. The available types are:

- EMG Channel: Contains EMG data.
- Processed EMG: Contains processed EMG data.
- Force Plate Channel: Contains information collected from force plates.
- Foot Switch Channel: Contains data collected from foot switches.
- Event Channel: Contains event data written to an analog channel.
- Other: All other channels not included in above categories.

Side – each EMG channel must be assigned a side (left, right, or none) in order to identify and group the various types of data for the selection in the analysis options.

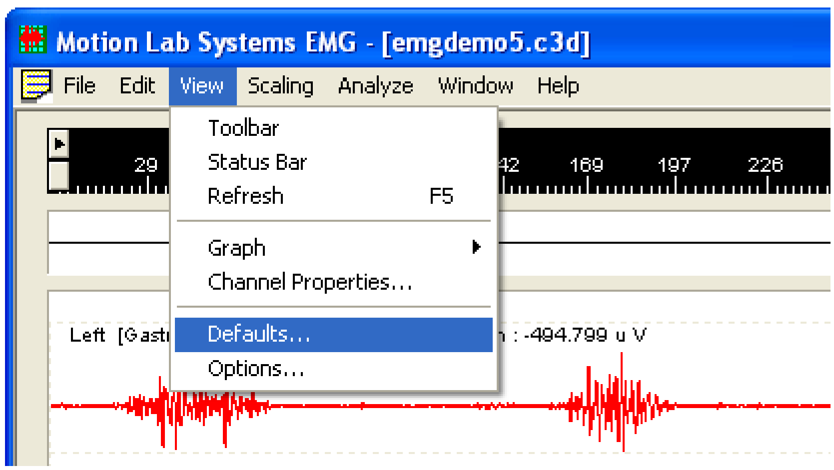
Selected – controls the display of the individual channels of EMG data. Channels that are *selected* will be displayed, while unselected channels will be hidden from the workplace displays. Other functions, such as various analysis and printing operations, will choose the selected channels by default although these choices can be changed if desired.

All changes made in the Channel Properties dialogs take effect as soon as the dialog box is closed.

Defaults

The *View:Defaults* sub menu is a tab based menu system that allows you to set all of the defaults for general appearance and operation of the ***EMG Analysis*** and ***EMG Graphing*** applications. These menus control the locations of the various files used by the programs as well as the general appearance of the applications and their interaction with the user. Changes made in these menus are stored and become the new defaults whenever the ***EMG Analysis*** and ***EMG Graphing*** applications are used in the future.

The *View:Defaults* menu does not affect any of the ***EMG Analysis*** or ***EMG Graphing*** operations, which are controlled via the *View:Options* sub menu.



The available pages are General Options, Channel Options, Graph Defaults, Colors and Events.

General Options menu

The General Options menu allows you to set some general options in the ***EMG Analysis*** and ***EMG Graphing*** applications that affect the way that the applications work. You may need to edit these values if the applications are not installed in their default locations.

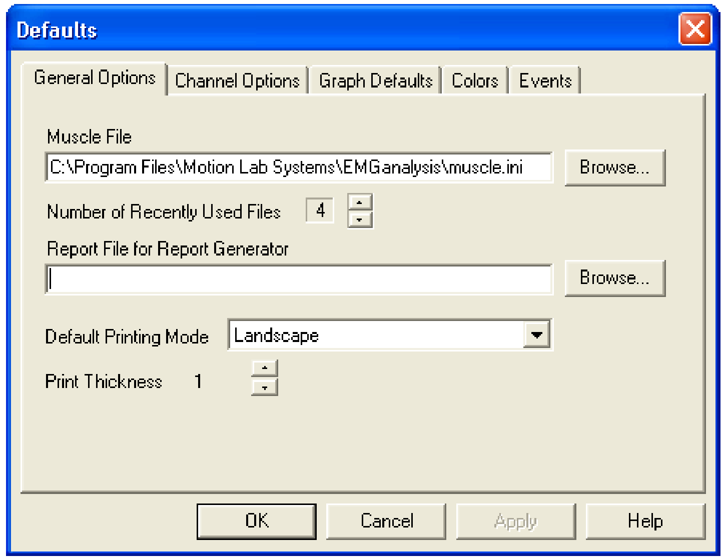


Figure 62 - The General Options menu

Muscle File - The muscle file stored the information about the ON/OFF states of different muscles during normal gait. The file name entered here sets the name of the file that is used by ***EMG Analysis*** and ***EMG Graphing*** applications to determine and display "normal activity" in the trial and analysis reports. Click on the ***Browse*** button to locate and select the muscle file in your computer. The default file name is supplied with a standard installation is muscle.ini – this is a text file that can be edited directly or via the Edit:Normal EMG Data interface built into the ***EMG Analysis*** and ***EMG Graphing*** applications.

Number of Recently used files - This is a control that allows you to set the number of recently used file names that the ***EMG Analysis*** and ***EMG Graphing*** applications will remember and display in the File menu. The range is from zero to eight.

Report File for Report Generator – This allows you to define a default report definition for use with the optional Motion Lab Systems *ReportGenerator* application for fully customizable reports.

Default Printing Mode – This allows you to set the default paper orientation when reports and trial displays are sent to the printer.

Print Thickness – This controls the thickness of the lines used to print the data – some high resolution printers may require that this number is increased from the default minimum of 1.

Channel Options menu

This Channel Options menu shown in Figure 30 allows you to enter some default information that can help identify the EMG and foot switch or event channels (if used) when a new EMG data file is first opened.

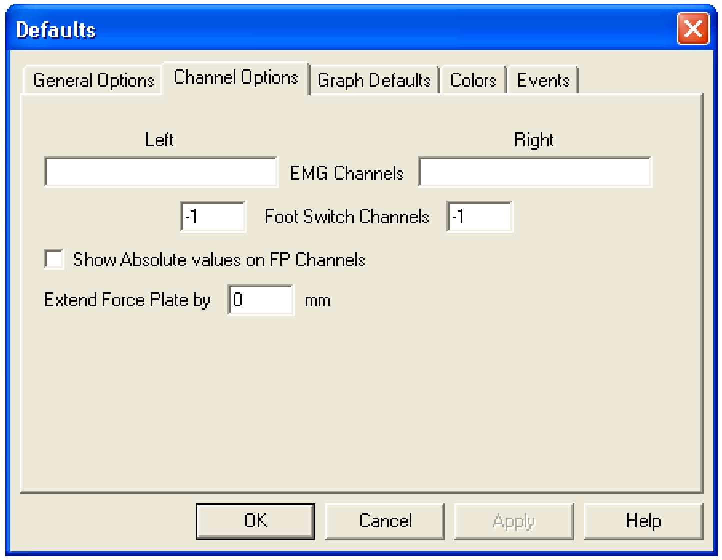


Figure 63 - Channel Options menu

When an EMG data file is first opened, all of the analog data channels are initially assumed to have a data in them of type OTHER – that is to say that initially we assume that the data in each channel is not assumed to be EMG data. The ***EMG Analysis*** and ***EMG Graphing*** applications then try to determine the type of data contained in the file by looking for the EMG:TYPE parameter (if it exists).

If the EMG:TYPE parameter does not exist, or it contains channels that are assigned as OTHER then the applications will analyze the label or identifier for these unassigned channels looking for labels that start with L or R (identifying the left or right side) and contain the string EM or EMG to indicate an EMG channel.

If this search results in channels that remain identified as OTHER then the ***EMG Analysis*** and ***EMG Graphing*** applications assign EMG channel identifiers using the four fields listed immediately below.

Left EMG Channels – This contains the default channel numbers for the EMG channels on the left side separated by commas.

Right EMG Channels - This contains the default channel numbers for the EMG channels on the right side separated by commas.

Left Foot Switch Channel - This is the channel number of the foot switch channel on the left side. Enter –1, if there is no foot switch channel.

Right Foot Switch Channel - This is the channel number of the foot switch channel on the right side. Enter –1, if there is no foot switch channel.

Although the ***EMG Analysis*** and ***EMG Graphing*** applications are primarily intended to display and analyze EMG information, they are both capable of displaying force data where it occurs in the EMG data file. By default, this data is displayed as scaled values. This default can be changed.

Show Absolute Values on FP Channels - If this box is checked, all the force plate channels will show the absolute value of the data present in the channels instead of the scaled values. This is normally unchecked and is provide as a courtesy for debugging purposes.

Extend Force Plate By - This is the number of millimeters by which the ankle or toe marker is allowed to be out of the force plate boundary when gait events are calculated using force plate information. You can extend this by a maximum of 20

mm to improve the ability of the ***EMG Analysis*** and ***EMG Graphing*** applications to detect gait events if the foot strike is close to the edge of the plate.

Graph Defaults menu

The Graph Properties menu controls the appearance of the EMG data. Options in this menu apply to all of the channels displayed in the trial view of the data.

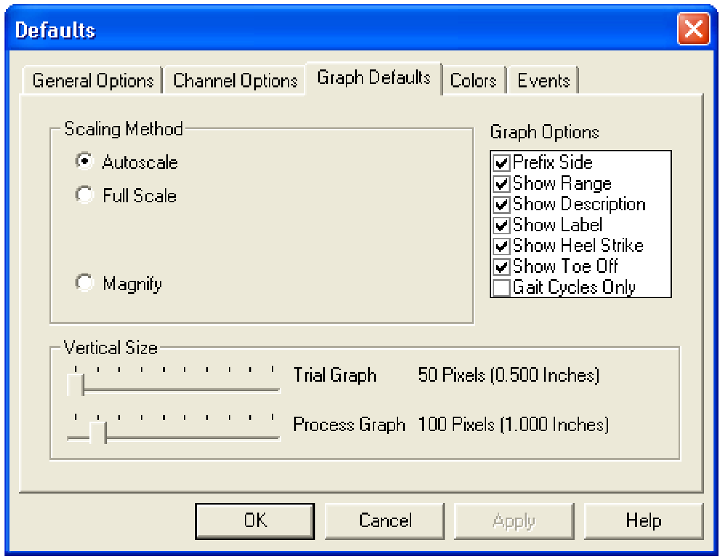


Figure 64 - The Graph Defaults menu.

The Scaling Method defaults allow you to decide how the data should be shown on the screen. These are relevant only when the whole trial is being viewed. Any changes made here will affect all open files. There are three methods that can be used:

- ***Autoscale –*** the default method of displaying the trial data – the auto scale method simply normalizes all the EMG data to the maximum and minimum value of the data found within each channel. This means that all EMG channels appear to be the same visual size regardless of the actual magnitude of the data.
- ***Full Scale –*** displays all EMG channels are displayed at the same scale – an EMG channel that contains a large signal will appear to be much larger than a channel that contains a small signal. Thus the displayed data will closely represent the actual differences in recorded signal magnitude. This display method requires that the ADC range and resolution are both entered correctly. If the entered ADC data range and resolution are incorrect then the displayed EMG data may be clipped or appear to be too small to appear in the display.
- ***Magnify –*** displays the trial EMG data after applying a magnification factor of between 1 and 10. This view is sometimes useful when debugging EMG data recording problems or investigating EMG data quality but this is not a display method that has any real clinical or research use. Note that in most cases, applying a magnification factor to normally recorded EMG data will cause the displayed data to clip – this occurs when the data becomes too large for the height of the display. As a result, the portions of the EMG data that lie outside the display area are “clipped” and are not visible. Since this command applies a selected magnification factor to the displayed data, it is impossible to tell whether the recorded EMG signals are actually clipped from the data display.

The Magnify display method, like the Full Scale and Auto scale methods, does not actually change the EMG data – the actual magnitudes of the different channel contents are preserved and can be displayed, together with the channel name, side and label in the trial view of the data.

- ***Vertical Size of Trial Graph -*** is a slider control that lets you set the vertical size of the EMG and other channels shown in the basic trial display **-** the range of values allowed is between 0.5 inches and 5.0 inches.
- ***Vertical Size of Process Graph -*** is a slider control that lets you set the vertical size of all of the analyzed data displays **-** the range of values allowed is between 0.5 inches and 5.0 inches.

The graph options allow you to control which labels, descriptions and event marks are shown in the trial plots. The available options are:

- ***Prefix Side -*** causes the side (Left or Right) that has been assigned to the channel to be displayed in the trial view of the data.
- ***Show Range –*** causes the maximum and minimum values (scaled or un-scaled) of the EMG data to appear on each channel in the trial view.
- ***Show Description -*** causes the description string associated with each channel to appear in the trial view – the description is usually used to record one of a number of standard muscle names.
- ***Show Label -*** displays the channel label associated with each individual channel. This is a unique label that identifies each individual channel.
- ***Show Heel Strike –*** This causes the Heel Strike to be drawn on both the trial and processed plots. The color used to display this line can be set on the colors menu page.
- ***Show Toe Off -*** This causes the Toe Off to be drawn on both the trial and processed plots. The color used to display this line can be set on the colors menu page.
- **Show Complete Gait Cycles** – checking this box will display only complete gait cycles in the Full Trial display.

Colors menu

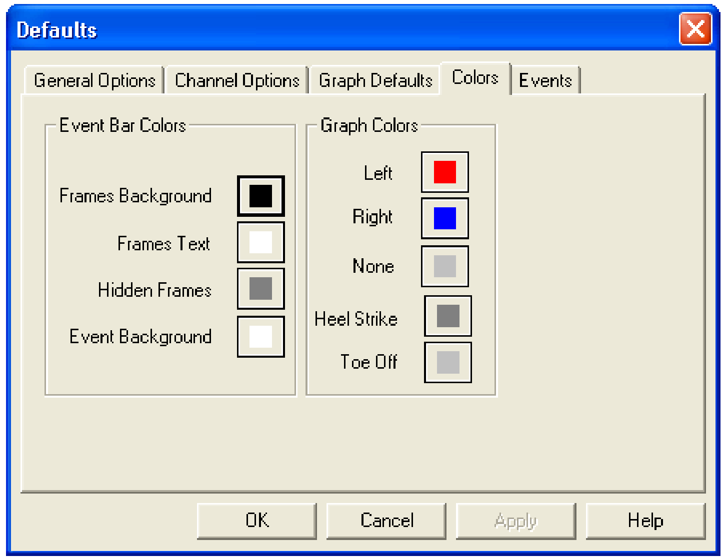


Figure 65 - Click on individual colors to customize the display.

The Colors menu allows you to customize the appearance of the ***EMG Analysis*** and ***EMG Graphing*** applications to use particular colors for different display elements. Clicking on any of the colors will display a standard dialog box that will allow you to pick a new color for any element displayed in the applications.

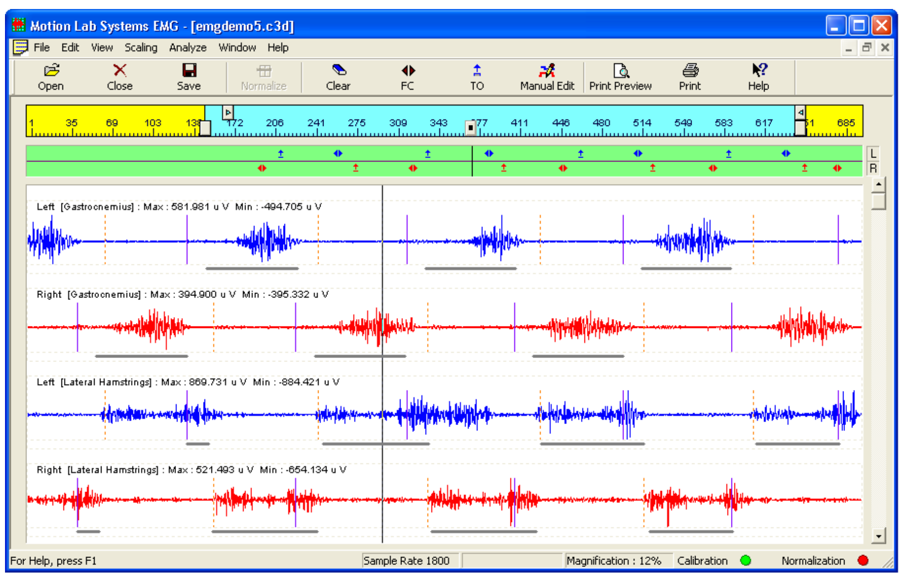


Figure 66 - The colors used by the EMG application can be customized to your needs.

In particular note that the colors used to indicate left and right side EMG traces can be set to match any specific conventions required in your lab while other elements in the colors scheme can be used to improve readability and or contrast for sight impaired or color-blind users.

Events Menu

The events menu enables the user to edit and create different event types. Events created here are compatible with the events format used by Vicon Motion Systems C3D files.

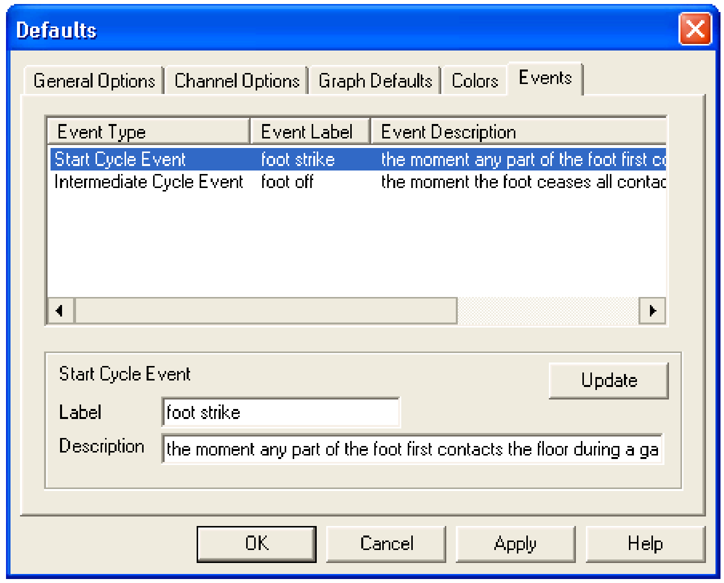


Figure 67 - The events menu

View Options

The View:Options menu controls the settings used by each of the analysis options in the ***EMG Analysis*** and ***EMG Graphing*** applications. Selecting the Options menu displays a dialog box that contains a list of all of the analysis functions supported by the full version of the ***EMG Analysis*** application. Selecting the individual analysis function from this list will display the available options and allow the electromyographer to make the appropriate selections.

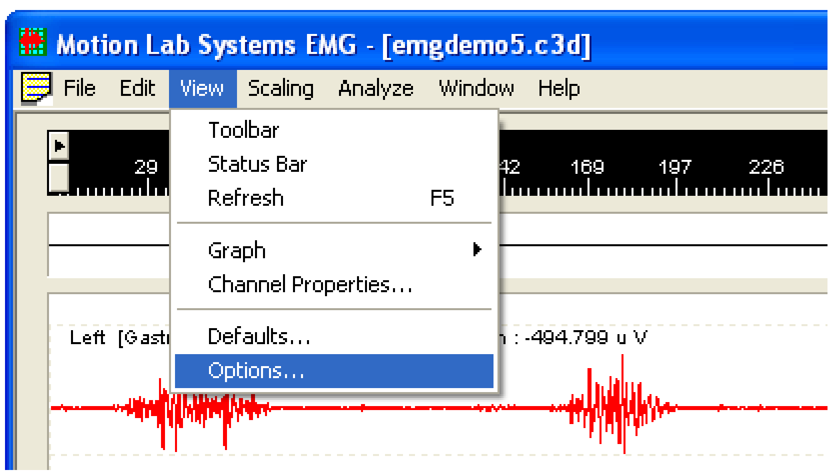


Figure 68 - Full control of the Analysis is available from the View:options menu.

Raw options

These controls the display of data in the raw EMG data analysis gait cycle graphs – there are two options:

Show as Percent of Maximum - causes the EMG data to be plotted as a percent of the maximum value found in the cycle – each EMG graph would be normalized to 100% of the maximum signal available within the gait cycle.

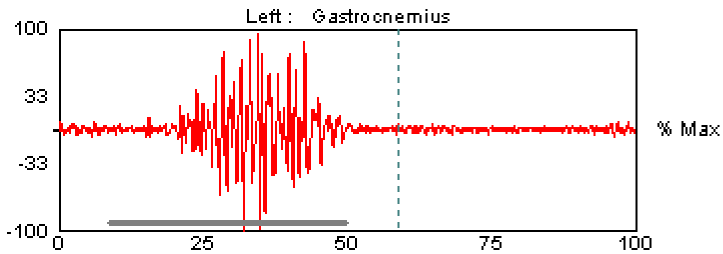


Figure 69 - Raw data normalized to 100%

If ***Show as Percent of Maximum*** is not checked then the actual recorded EMG voltages will be displayed. Assuming that the analog data parameters were specified correctly when the data was recorded then this will be either the actual voltages present at the ADC or, if the data has been calibrated, in skin surface levels. Skin surface EMG levels are usually expressed in millivolts (mV) or microvolts (uV).

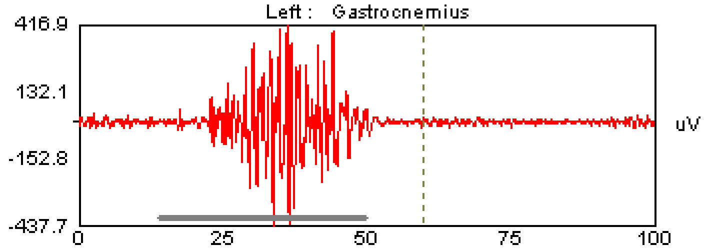


Figure 70 - Raw data displayed as voltages at skin surface (calibrated).

Note that all that has changed between the two displays is the scaling of the data. In the EMG data has not been calibrated then the data will usually be displayed with a range of ±5 Volts or ±10 Volts if the analog data scaling values were set correctly when the data was recorded. If you are unscaled seeing raw data values that are outside these ranges then the original ADC scaling parameters may need to be corrected.

Plot Data between – causes the raw EMG data to be plotted over a specific voltage range entered in this menu. This allows you to see the relative strength of the data collected in all the channels, as all of the data will be plotted to the same fixed scale.

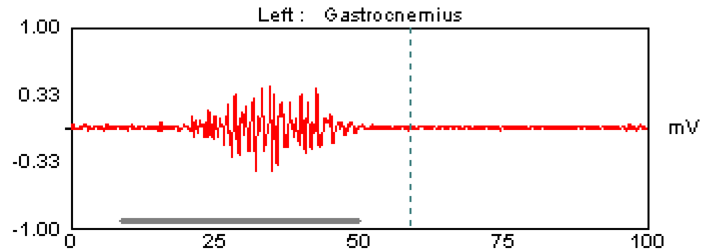


Figure 71 – Raw data plotted between plus and minus 1mV.

When entering the display range remember that calibrated EMG data is usually scaled in thousandth of a Volt (enter 0.001 for 1mV range), while un-calibrated data directly from the ADC is usually measured in Volts.

Full Wave Rectified menu

Show as Percent of Maximum - causes the EMG data to be plotted as a percent of the maximum value found in the cycle – each EMG graph would be normalized to 100% of the maximum signal available within the gait cycle.

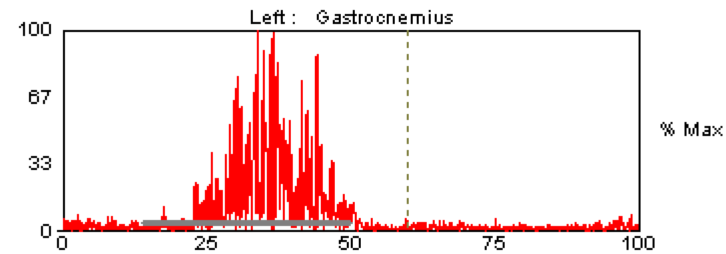


Figure 72- Full Wave Rectified data normalized to 100%

If ***Show as Percent of Maximum*** is not checked then the actual recorded EMG voltages will be displayed. Assuming that the analog data parameters were specified correctly when the data was recorded then this will be either the actual voltages present at the ADC or, if the data has been calibrated, in skin surface levels. Skin surface EMG levels are usually expressed in millivolts (mV) or microvolts (uV).

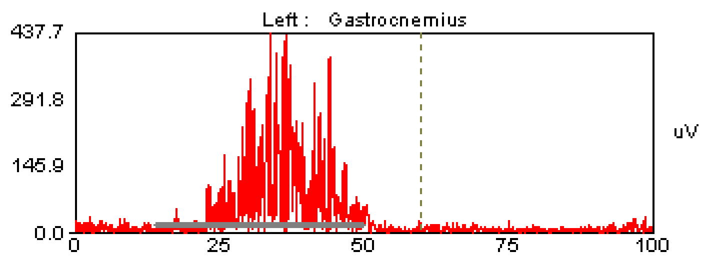


Figure 73 - Full Wave Rectified data displayed as voltages at skin surface (calibrated).

The voltage range for Full Wave Rectified data will always be scaled to the absolute value of the EMG data – thus the maximum value may be greater than the maximum positive value of the raw signal. This is a normal result of the rectification process.

Plot Data between – causes the raw EMG data to be plotted over a specific voltage range entered in this menu. This allows you to see the relative strength of the data collected in all the channels, as all of the data will be plotted to the same fixed scale. When entering the display range remember that calibrated EMG data is usually scaled in thousandth of a Volt (enter 0.001 for 1mV range), while un-calibrated data directly from the ADC is usually measured in Volts.

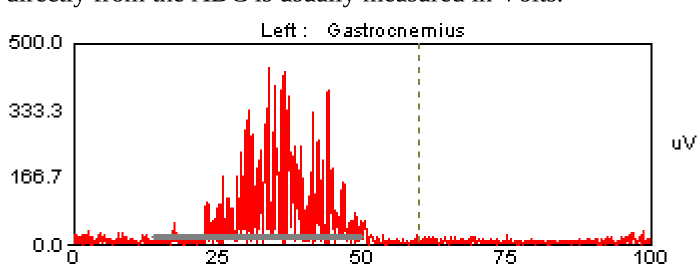


Figure 74 - Full Wave Rectified data plotted between 0 and 0.5mV (calibrated data).

Moving Average menu

The Averaging functions are only available in the EMG Analysis program.

The Moving Average Options enable the user to describe and control the processing of the rectified EMG signal using a moving window averaging method. This smoothing option is calculated within the specified window of data points – the result is a smoothed series of data points as the window (described in terms of a period of milliseconds) moves through the rectified data.

The display will consist of a single smoothed envelope drawn with a solid line representing the moving average of the current EMG activity period. Where multiple periods of EMG activity are defined via events in the trial data then the standard deviation of the averaged periods will be calculated and displayed with a pair of dashed lines. It should be noted that while the *Moving Average* is a common method of displaying and averaging envelope data it is of limited significance in the clinical environment as the averaging process tends to extend the perceived period of EMG activity by advancing the apparent start of activity and retarding the cessation of activity. The right click menu available via any mouse click within the graphical analysis display window allows the user to select any one of multiple EMG periods to display as the solid line.

The following options are available for the Moving Average process:

Size of window - this is the size of the moving window measured in milliseconds and can be adjusted to produce the desired amount of data smoothing. This type of filter will always have a delay or phase lag that is equal to the window length because the window must fill before any data points can be generated. Thus it is very important that the moving average window period is described whenever data processed with the Moving Average is presented.

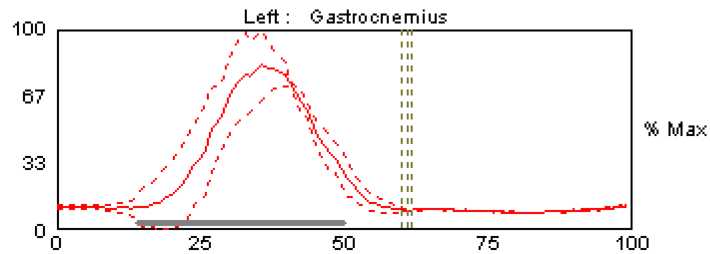


Figure 75 - Moving Average display with 150ms window scaled to 100%

Increasing the moving average period will increase the amount of smoothing of the output data and increase the phase lag. Decreasing the window period will reduce the amount of smoothing and the corresponding phase lag of the displayed data.

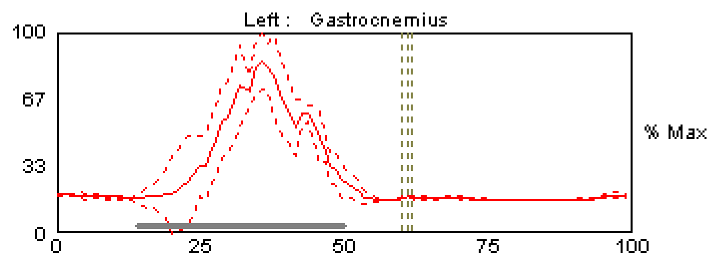


Figure 76- Moving Average display with 50ms window scaled to 100%

Points to Output - is the total number of points that will be written to the GCD output file when the moving average is output. These data points are produced by a process of interpolation of the moving average output so that data from two or more periods of EMG activity can be averaged. The allowable range is from 51 to 501 points.

Show as Percent of Maximum - causes the averaged EMG data to be plotted as a percent of the maximum value found in the cycle – each EMG graph would be normalized to 100% of the maximum averaged signal available within the gait cycle. If this option is not checked then the actual Moving Average values, calculated by the process, will be displayed in terms of microvolt seconds.

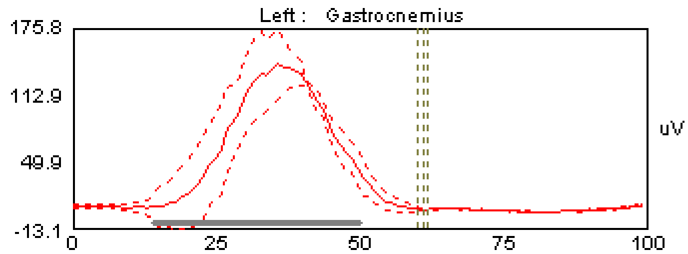


Figure 77 - Moving Average display (150ms) scaled in microvolt-seconds.

Linear Envelope menu

The Linear Envelope option is only available in the EMG Analysis program.

The Linear Envelope Processing Analysis processes the rectified raw EMG signal with a Low Pass digital filter with a specified cutoff frequency. The display will consist of a single smoothed envelope draw with a solid line representing the moving average of the current EMG activity period.

Where multiple periods of EMG activity are defined via events in the trial data then the standard deviation of the averaged periods will be calculated and displayed with a pair of dashed lines. Both *Linear Envelope* and *Moving Average* envelope methods are common methods of displaying and averaging envelope data however they are of limited significance in the clinical environment as the averaging process tends to extend the perceived period of EMG activity by advancing the apparent start, and prolong the end, of the reported muscle activity.

The right click menu available via any mouse click within the graphical analysis display window allows the user to select any one of multiple EMG periods to display as the solid line.

The Linear Envelope analysis function includes the following options:

Cut Off Frequency - is the cut off frequency in Hertz (cycles per second) for the low pass filter that will be used. The value entered should be greater than zero – typically a value of 6Hz is used.

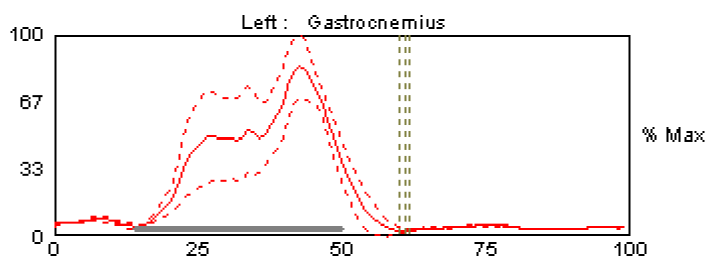


Figure 78 - Linear Envelope display - 6Hz, single pass, filter scaled to 100%

Passes – this option allows the user to use either a single pass filter or a dual pass filter. The dual pass filter removes any phase shift that is caused by the filtering operation and is the optimum selection.

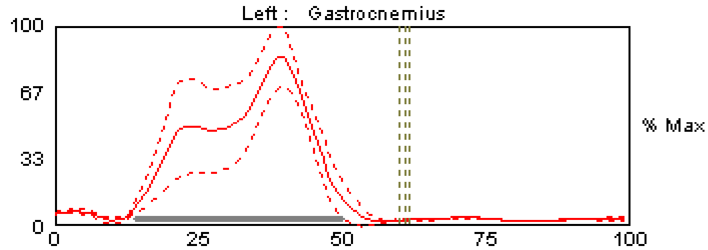


Figure 79 - Linear Envelope display - 6Hz, dual pass, filter scaled to 100%

All single pass filters have an associated phase lag (or delay) that varies with the degree of filtering and the filter cutoff frequency. The Linear Envelope process includes an option to run the filter as a dual pass digital filter – dual pass filters are zero-delay filters that do not introduce a phase lag or delay into the output data from the process.

Number of points to output - is the total number of points that will be written to the GCD output file when the moving average is output. These data points are produced by a process of interpolation of the moving average output so that data from two or more periods of EMG activity can be averaged. The allowable range is from 51 to 501 points.

Show as Percent of Maximum - causes the averaged EMG data to be plotted as a percent of the maximum value found in the cycle – each EMG graph would be normalized to 100% of the maximum averaged signal available within the gait cycle. If this option is not checked then the actual Moving Average values, calculated by the process, will be displayed in terms of microvolt seconds – assuming that the data is calibrated in terms of volts at skin surface.

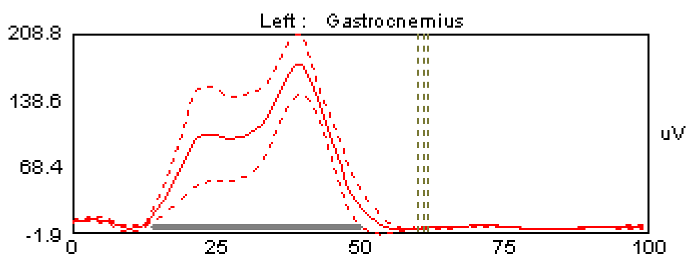


Figure 80 - Linear Envelope display - 6Hz, dual pass, scaled in microvolt seconds.

RMS Analysis menu

This option is only available in the EMG Analysis program.

The RMS (Root Mean Square) Analysis differs from the Moving Average and Linear Envelope analysis methods in that it starts with raw EMG data instead of rectified EMG data.

The RMS analysis performs the following operations on the raw EMG data. A high pass filter with a user selectable cutoff frequency (usually in the range of 1 to 20Hz) is applied to the raw EMG data to remove any DC offset in the data stream. A root mean square value for the EMG data stream is then processed (the raw EMG data values are squared and then the square root calculated) and the resulting output is then averaged over a selectable period, usually in the range of 20 to 499 milliseconds.

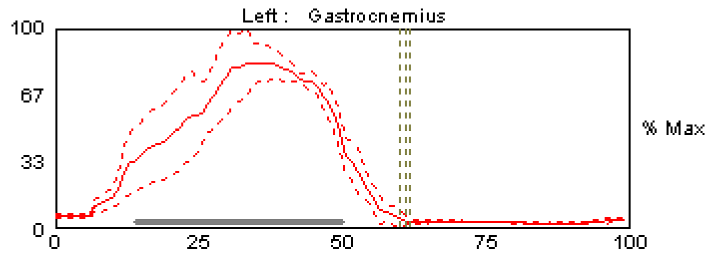


Figure 81 - RMS analysis with 5Hz HPF and a 200ms window

Where multiple periods of EMG activity are defined via events in the trial data then the standard deviation of the averaged periods will be calculated and displayed with a pair of dashed lines. The right click menu, available via a mouse click within the graphical analysis display window, allows the user to select any one of multiple EMG periods to display as the solid line for comparison.

The analysis menu provides the following options:

Size of window **-** this is the size of the moving window measured in milliseconds and can be adjusted to produce the desired amount of data smoothing. This type of filter will always have a delay or phase lag that is equal to the window length because the window must fill before any data points can be generated. Thus it is very important that the moving average window period is described whenever data processed with the Moving Average is presented at this affects the timing of the reported EMG activity. The window size can be preset to any value between 20 and 499ms.

Number of points to output **-** is the total number of points that will be written to the GCD output file when the moving average is output. These data points are produced by a process of interpolation of the moving average output so that data from two or more periods of EMG activity can be averaged. The allowable range is from 51 to 501 points.

HPF Cutoff Frequency **-** is the cutoff value of the High Pass Filter that is applied to the raw EMG data prior to RMS processing. The filter cutoff frequency should be set to a value between 0.1Hz and 80Hz.

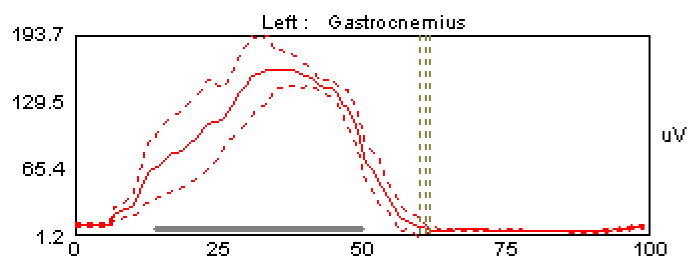


Figure 82 - RMS Analysis (5Hz, 200ms)scaled in microvolt seconds

Show as Percent of Maximum **-** causes the averaged EMG data to be plotted as a percent of the maximum value found in the cycle – each EMG graph would be normalized to 100% of the maximum averaged signal available within the gait cycle. If this option is not checked then the actual Moving Average values, calculated by the process, will be displayed in terms of microvolt seconds – assuming that the data is calibrated in terms of volts at skin surface.

Intensity Filtered Average menu

The Intensity Filtered Average analysis option is

This menu allows you to set the options for the Intensity Filtered Average (IFA) process which is based on the algorithm described in the paper *Computer Algorithms*

only available in the EMG Analysis program.

to Characterize Individual Subject EMG Profiles During Gait published in 1992 by Ross Bogey, Lee Barnes, and Jacquelin Perry, MD.

This paper describes a processing method based on both the timing and the relative amplitude of the EMG signal that generates better results than the standard Moving Average or Linear Envelope methods. It is proposed that the IFA method generates an envelope output that more closely represents the onset, duration, and cessation of the subjects muscle activity.

The Intensity Filtered Average method differs from the various enveloping analysis methods because it excludes brief EMG activity bursts (less than 5% of the gait cycle or EMG period), and activity below a preset threshold, from the averaging process. Averaging methods used by the Window, Linear Envelope and RMS analysis methods all generate activity envelopes that include all of the available EMG data. The rational for the IFA method is that by excluding relatively low level EMG activity from the envelope and averaging process, the results better reflect the essential muscle activity during gait as the low intensity and short duration bursts have very little effect on the joint motion.

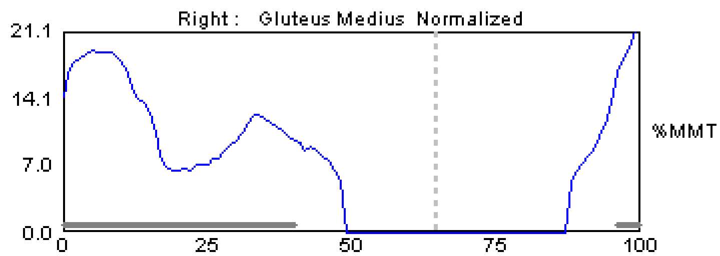


Figure 83 - IFA analysis requires normalized trial data.

IFA processing requires that data from maximum manual muscle test (MMT) recordings are available for each muscle prior to performing the IFA analysis. As a result the IFA option will only appear in the Analysis menu when the current file has been normalized. In addition, since the process requires that each muscle is normalized, the IFA analysis will only display an analysis for those muscle that have been normalized. Muscles that have not been normalized and do not have normalization data applied (i.e. a Green Normalization status in the EMG status bar at the bottom of the EMG Analysis window) will not be displayed in the Analysis output page.

***Size of window* –** This is the size of the envelope moving window in milliseconds.

***Zero values less than(%MMT)* –** This is the threshold value below which the EMG activity is removed from the averaging process. The value entered here should be between 0 and 100 and is generally a fairly low level – the paper defining this method uses a value of 5% of the applicable muscles maximum manual muscle test recording.

Threshold Detector menu

The Threshold Analysis option is only available in the EMG Analysis program.

The Threshold Analysis processes the EMG signal and outputs data that indicates when the EMG signal exceeds a number of preset threshold values. The rectified EMG signal is then processed via the Moving Average or Linear Envelope analysis functions and an output generated whenever the envelope data values exceed the preset thresholds.

In addition to displaying the threshold timing values, the threshold analysis display allows the user to overlay the raw EMG data over the threshold display. This allows the user to verify that appropriate threshold levels have been selected and adjust the

settings if necessary. The colors used to display the thresholds can be chosen whenever the Threshold options dialog box is opened.

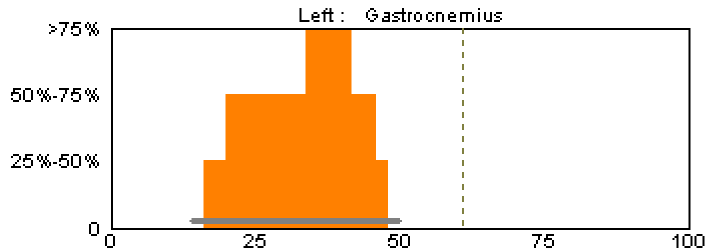


Figure 84 - Threshold detector with threshold levels at 25%, 50%, and 75%

The Threshold Detector option menu has all the options necessary for the creation of the levels that will be used by the Level Detector and the control of the displayed results. These options are:

Create Using **-** allows the user to select the envelope creation method – this can be either the Moving Window, or Linear Envelope analysis method. The parameters for each envelope method are identical to those set by each of the envelope options. If you need to change the default values then simply set the properties for the appropriate envelope method using the envelope options menu.

Points to output **-** is the total number of points that will be written to the GCD output file when the moving average is output. The range for the threshold output data is from 10 to 50 data points.

Overlay Raw Data on Detector **-** allows you to overlay the raw data from the selected cycle on to the detector plots. When this option is selected the raw EMG data for the current EMG period will be displayed over the threshold display.

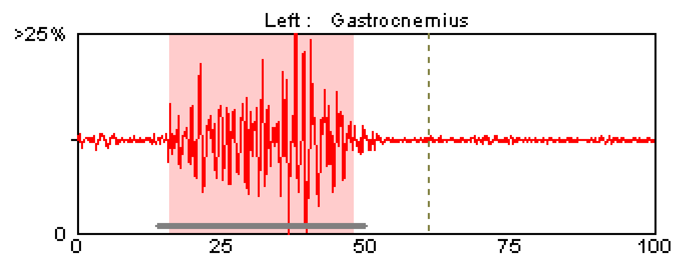


Figure 85 – Threshold analysis (25%) with raw EMG signal overlay.

Number of Levels **-** is the number of levels that are to be used. This can be from 2 to 10 levels. If you have chosen to display *n* levels then you can choose the values for *n*-1 levels using a slider control for each threshold level. The values for the levels should be set in order from the first level through to the last. The value of each level must be greater than that of the previous level and lesser than that of the next level.

Threshold'n' **–** displays and adjusts the current threshold levels – note that the method of counting levels here means that if you select two threshold levels then you will have one threshold slider displayed. Adjusting this slider will set the threshold setting to report envelope values that are *greater than* and *less than* the chosen value.

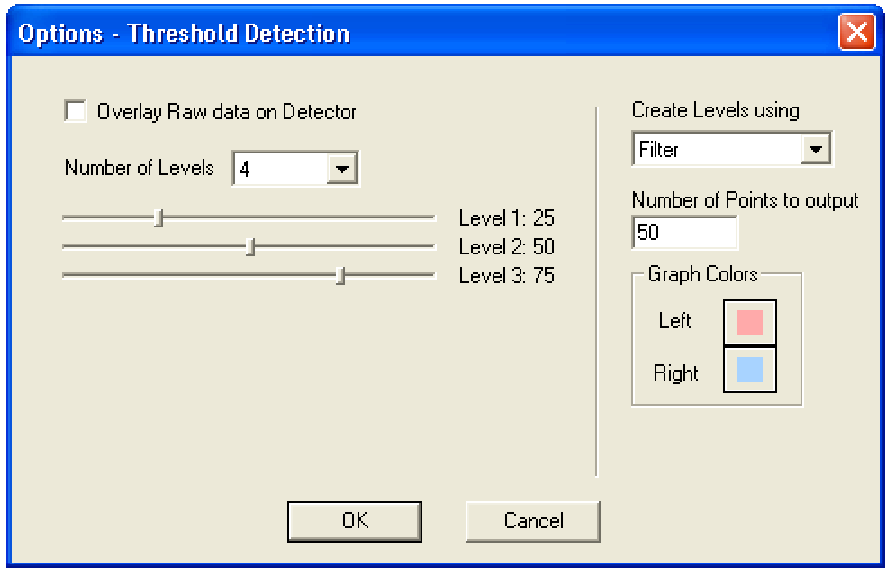


Figure 86 - The colors used to display the threshold data can be set within the options menu.

Graph Colors – you can select the colors used by the threshold display whenever the options menu is shown. The detector levels will be filled with the color that you select - you can either click on the button with the desired color or define a custom color – in general it is best to define lighter colors when the *Overlay Raw* option is used.

Zero Crossing menu

This option is only available in the EMG Analysis program.

The Zero Crossing Analysis describes EMG activity by detecting and displaying the number of times that the raw EMG signal crosses the zero. This analysis method has a single option that controls the software comparator used by this method.

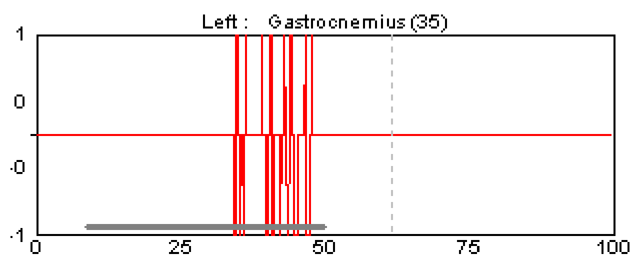


Figure 87 - Zero Crossing with 30% hysteresis.

Hysteresis – is measured in percent and controls the amount of hysteresis in the comparator function used by the zero crossing analysis. Hysteresis is the difference between the EMG signal level input and the DC zero level and setting this parameter controls the point at which the comparator turns off and turns on.

The total number of Zero Crossings for the analyzed period is displayed after the muscle name. High values for the comparator hysteresis value reduce the number of zero crossings that are detected, while lower hysteresis values increase the number of detected zero crossings.

Integrate over Time menu

This option is only available in the EMG

The Integrate over Time Analysis is performed on the rectified raw EMG signal. This process of integration over time produces an output that is proportional to the

Analysis program.

level of the EMG signal over a given period that the user can select. The integration process sums the rectified EMG values for the selected time period – at the end of the time period the signal output is reset to zero and the integration process restarted.

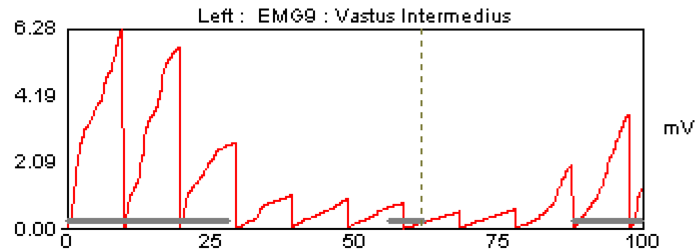


Figure 88 - Integrate over Time with 100ms reset interval.

Time Interval – this option defines the integration period in milliseconds and must be set to a value between 1ms and 2000ms (2 seconds). Typical values are between 10 and 200ms depending on the activity period under investigation.

Integrate and Reset menu

This option is only available in the EMG Analysis program.

The Integrate and Reset Analysis is performed on the rectified raw EMG signal. This process of integration and reset produces an output that is proportional to the level of the EMG signal. The integration process sums the rectified EMG values until the EMG reaches a set percentage of the average level – once this level is reached the signal output is reset to zero and the integration process restarted.

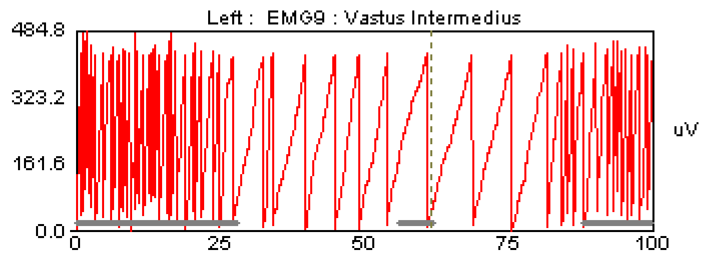


Figure 89 - Integrate and Reset at 300%

EMG Power Spectrum

This option is only available in the EMG Analysis program.

The Power Spectrum Analysis option calculates the Power Spectrum of each EMG channel and displays it together with the Mean and Median frequencies. As a result it is essential that the signal that is processed by this function is a clean EMG signal without any clipped data that would introduce frequency distortions. In addition, and filtering of the signal, prior to analysis should be documented.

Processing EMG data that is clipped will produce spectral results that do not accurately reflect the signal content of the EMG signal – any clipping will result is spurious high frequencies that will distort the spectral displays. In a similar manner, the presence of background noise in the EMG signal, or the inclusion of large periods of inactive baseline in the FFT processing window will tend to produce results that appear to indicate spurious high frequency EMG activity.

Processing EMG data that has been recorded with too low a sample rate will result in problems too – the low sample rate will result in the EMG spectrum appearing to stop at a much lower frequency than in real life and, if the data was not low pass filter correctly prior to sampling, will result in spurious signals being generated throughout the recorded spectrum as a result of signal aliasing. For these reasons it is recommended that the EMG signal is sampled at least four times faster then required

to sample the expected EMG signal. In addition the analog signal must be adequately filtered prior to data sampling to eliminate the possibility of sampling errors due to aliasing.

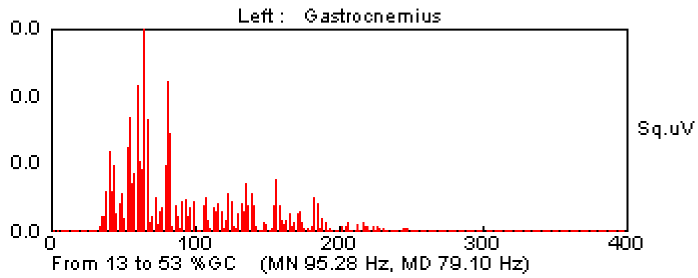


Figure 90 - The power spectrum shows the EMG frequency distribution.

The Power Spectrum Analysis features a number of options that control the analysis and display of the graphical data. These are

***Analog Channel*s –** check the boxes for the channels that you would like processed via the Power Spectrum Analysis. This will default to the displayed EMG channels when the Analysis is first started so if you want to limit the number of channels or add additional channels then you will need to modify these selections.

Window Start (%GC) – By default we use the EMG signal to determine the portion of the defined EMG period to be analyzed. If you would prefer to analyze a specific portion of the EMG period then you can define the start and end of the FFT analysis window here (and the *Window End* entry below) and then uncheck the "*Use EMG signal to determine FFT window*" box below.

Window End (%GC) – This defines the end of the FFT analysis window described above. It is only used if the *Use EMG signal to determine FFT window* option is not checked.

Plot Spectrum From – You can select the range of frequencies over which the EMG FFT Spectrum Analysis is performed. The start frequency is entered in this box while the ending frequency is entered in the box below.

Plot Spectrum Till – This box defines the upper end of the EMG frequency analysis bandwidth as discussed above.

This is the default EMG Spectrum Analysis method.

Use EMG signal to determine FFT window – The FFT analysis is normally performed over a defined period so that the results reflect the spectrum content of the EMG burst and do not include periods of quiescent activity that would otherwise affect the results. The FFT analysis period can be defined in two ways, either by setting a specific, fixed portion of the defined EMG period (or Gait Cycle) to be processed, or else by performing the FFT analysis over the period that the EMG Analysis software has determine activity to occur. We use the basic EMG window envelope analysis to define the portions of the EMG cycle to analyze and set the analysis threshold via the option below.

Ignore signals below [nn]% – When the FFT analysis period is defined by the EMG signal as described above this option allows the user to set a threshold below which the EMG signal will be ignored. This allows the user to remove the inactive EMG baseline period from the FFT Spectrum processing to generate spectral analysis data that more closely reflects the content of the active EMG burst – thus excluding inactive noise signals from the results. In general values between 5% and 20% work well here to restrict the FFT analysis to the active portion of EMG activity.

Number of sub divisions on X Axis – This simply defines the number of frequency divisions displayed along the horizontal spectrum analysis graphs.

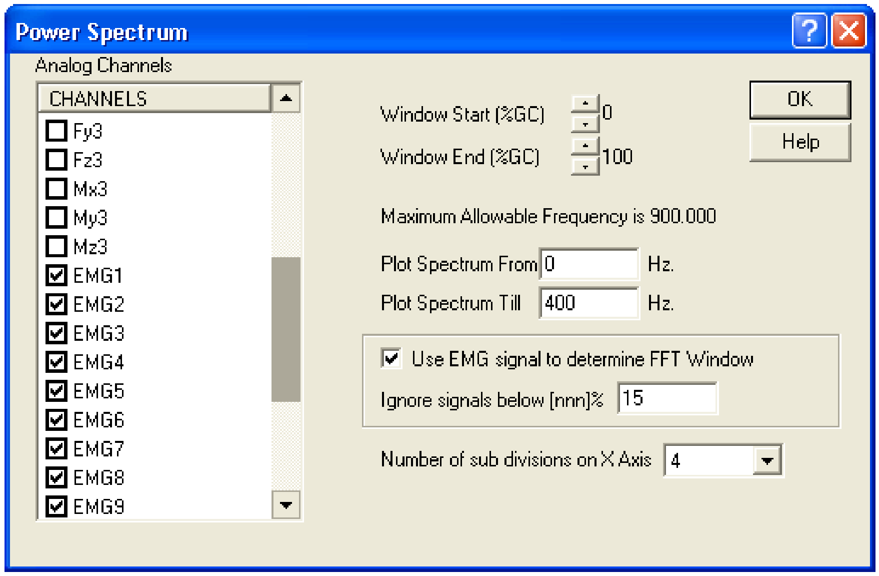


Figure 91 - The Power spectrum options panel.

EMG Amplitude Distribution menu

This option is only available in the EMG Analysis program.

The Amplitude Distribution Analysis measures the amplitude density function of all of the EMG channels and displays the amplitude distribution of the EMG signal representing the relative percentage of time that the EMG signal is at a given amplitude. In this analysis the range of EMG amplitudes is plotted across the horizontal axis while the total time at each level is plotted along the side.

While this analysis requires that the analysis period is defined by two start (FC) and stop (FC) events, it is not generally used in analyzing gait cycles as it is more useful in looking at activity over a longer period.

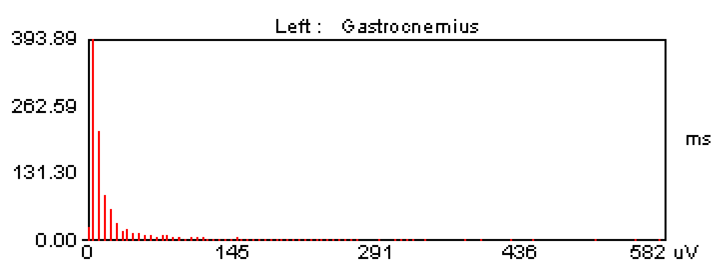


Figure 92 - The Amplitude Distribution Analysis showing light activity

High levels at the left side of the graph (lower EMG levels) indicate that EMG activity is relatively light whereas the further the activity extends to the right side of the graph suggests a greater degree of muscle activity. Most amplitude distribution graphs will display either resting activity (a single peak to the left) or a double peak indicating both resting and work periods within the analyzed EMG recording.

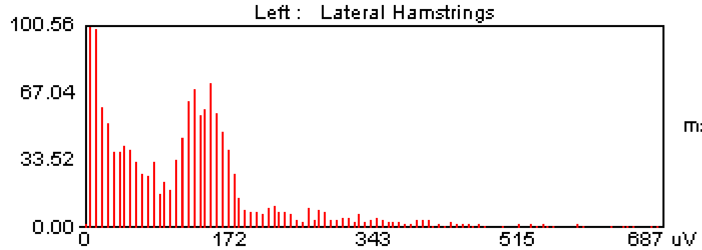


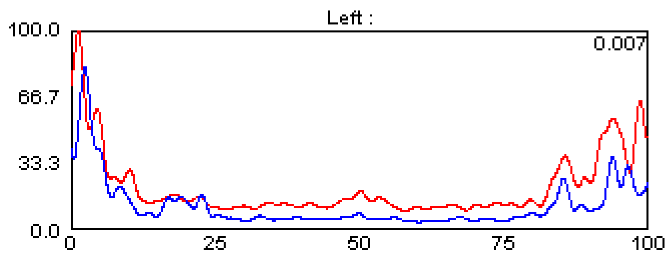
Figure 93 - An Amplitude Distribution showing rest and work activity.

Amplitude Distribution analysis is a useful tool in biofeedback and relaxation analysis as well as an investigation into muscle activity and ergonomics. Some studies have indicated that workers whose amplitude distributions are strongly skewed to the right tend to report more muscle pain than others.

Cocontraction menu

This option is only available in the EMG Analysis program.

The Cocontraction Analysis allows you to view the degree of correlation between pairs of muscles.



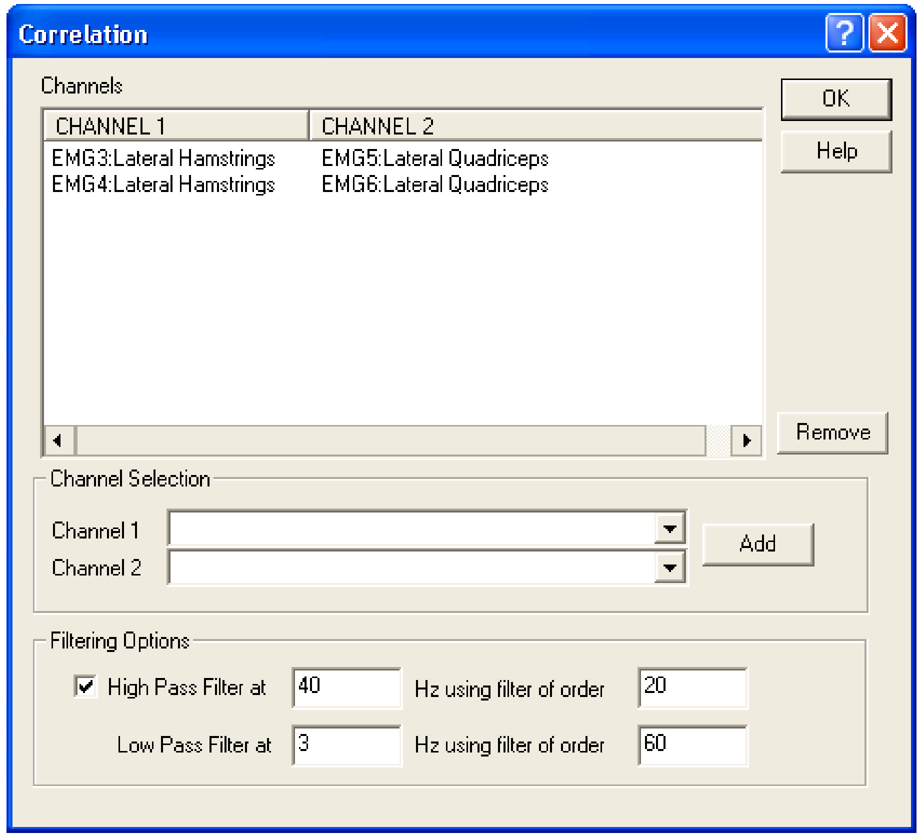


Figure 94: Correlation dialog box

This dialog box has the following controls:

Channels

This is a list control that has two columns that will show the EMG channels to be correlated against each other. There will be no EMG channels in the box initially. To add two channels to be correlated, click on the Add button. By default both channels will be the first analog channel. To change this, double click on the channel name. This will give you a list of all the channels. Both the channels should be from the same side.

Channel 1

This box lists all the EMG channels in the file. Select a channel from this drop box.

Channel 2

This box lists EMG channels from the same side as the channel selected in Channel 1.

Add

This will Add a new channel pair to the Channels box. Click on this button after you have made a selection in the Channel1 and Channel2 boxes.

Remove

This button removes the selected channel pair from the Channels box.

Filtering Options

The filtering options will be applied to the selected EMG channels prior to the correlation analysis. Note that, while the high pass filter is optional, the low pass filter setting is required.

Aliasing menu

This option is only available in the EMG Analysis program.

The Aliasing option in EMG Analysis and EMG Graphing is a diagnostic option that provides a fixed FFT analysis of the frequency spectrum from 1Hz to 20Hz. This is outside the normal EMG bandwidth and examining this portion of the frequency spectrum can help determine if Aliasing occurred during the original data collection. Unlike every other Analysis option, the aliasing analysis processes each EMG channel in full – it does not require that an analysis period is defined by preexisting events.

The theory that this analysis option uses is that aliasing errors, in the form of spurious output frequencies from the EMG data, will occur throughout the recorded frequency spectrum – producing spectral data in portions of the spectrum that we would expect to be empty.

How you use and interpret the results of this analysis will depend on the precise bandwidth of the EMG system used and any subsequent processing of the data – which, for this analysis to work, should be minimal. Specifically, high-pass filtering the EMG data prior to performing an aliasing analysis will remove the signals that we are testing for – so don't high pass filter the data prior to this analysis.

The interpretation of the data will depend on the bandwidth of your EMG signal – it would be quite normal to see output in the 8 to 20Hz range if your EMG system has a frequency response that goes down to 10Hz for example. However, if the aliasing analysis reports frequencies in the 1 to 5Hz range with this system then aliasing is indicated. Generally aliasing signals will appear spread through out the entire EMG signal frequency spectrum – the *Aliasing Analysis* simply looks specifically in a part of the frequency spectrum that we expect to be empty.

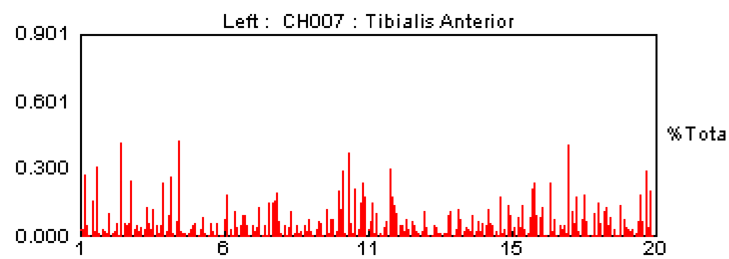


Figure 95 - Aliasing occurred in this channel producing spurious signals.

Since this analysis is not something that you will generally use, it does not appear as an option in the right-click analysis menu list. It is only available from the main toolbar Analysis menu.

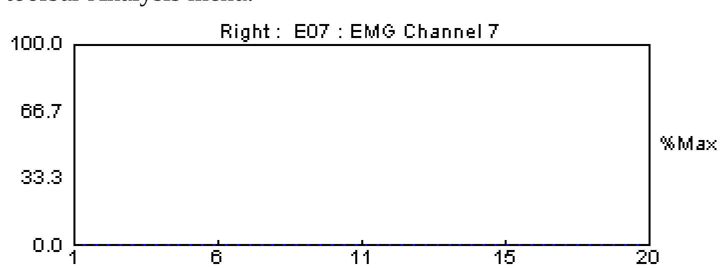


Figure 96- No aliasing detected in this EMG channel.

The Aliasing analysis has three options:

Start Frequency – specifies the lowest frequency to start plotting. This value must be less than the value chosen for the end frequency – the default is 1Hz which stops the aliasing results being affected by any DC bias in the input signal..

End Frequency – specifies the highest frequency to be plotted. This value must be greater than the value chosen for the start frequency – the default is 20Hz which is suitable for EMG channels that have a bandwidth down to 20Hz. Remember that different EMG channels may have different frequencies responses depending on the system configuration.

Aliasing Method – allows the choice of one of a number of different alias detection methods – these are, Percent of Maximum Power, Percent of Total Power, Value and Value (auto). Percent of Maximum Power is the default method and generally produces the best results.

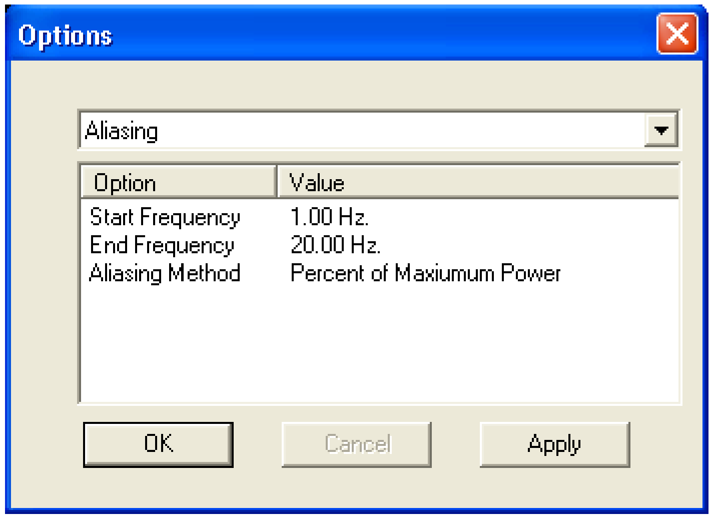


Figure 97 - The aliasing analysis options menu

The Aliasing analysis feature is useful in many cases but is not foolproof – it can show the presence of aliasing errors but can not be used to prove that aliasing did not occur. Aliasing errors resulting from external interference (a single interfering frequency at, for example 400Hz in data sampled at 700Hz) will not be reported. Nevertheless, many common problems – such as aliasing resulting from the choice of too low an analog sampling frequency, or aliasing due to external noise sources in the EMG signal – will be reported and steps can be taken to deal with the problems. Remember that aliasing is simple the result of the data presented to the analog recording system changing faster than the system can accurately record – aliasing does not necessarily tell you anything about the EMG signal.

The Scaling Menu

The ***EMG Analysis*** and ***EMG Graphing*** applications offer a variety of different methods of scaling and calibrating the EMG data – these are controlled via the Scaling menu.

The Scaling menu allows the electromyographer to remove or apply scaling to the EMG data as well as providing two methods for calibrating the data – calibration is generally used to enable the EMG data to be displayed as skin-surface or sensor input levels.

In addition, the EMG data can be Normalized (usually to Maximum Voluntary Contraction or MVC) from this menu. Note that Normalization and Calibration are two mutually exclusive operations so the Normalization menu is only accessible if the current file has not been calibrated, or if the current calibration is turned off.

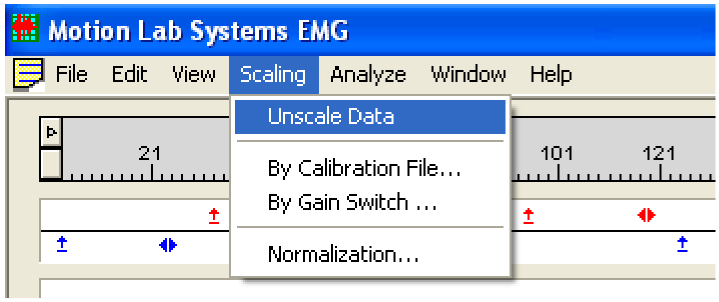


Figure 98 - the Scaling menu offers calibration and normalization options.

The calibration and normalization status of the current file is displayed by colored indicators on the status bar, at the bottom of the ***EMG Analysis*** and ***EMG Graphing*** application window – see Figure 67. The color of these indicators indicates any one of a variety of calibration/normalization status situations:

- ***Gray*** – indicates that there is no active calibration data or any normalization data files. The display is un-calibrated and/or is not normalized.
- ***Red*** – indicates that there is no calibration data or normalization information in the active file.
- ***Green***: This means that calibration or normalization data is present, is being used by the application and will be recorded when the file is saved. It is important to note that while both calibration and normalization values can be stored within a file, only *one* can be applied at any given time – the data can not be both calibrated and normalized at the same time.
- ***Yellow***: This means that calibration and/or normalization data is present, but is not being used by the application. As a result, the displayed EMG data will not be calibrated and/or normalized.
- ***Yellow-Green***: This means that calibration data is present and is being used by the application for some EMG channels and is not being used for others.

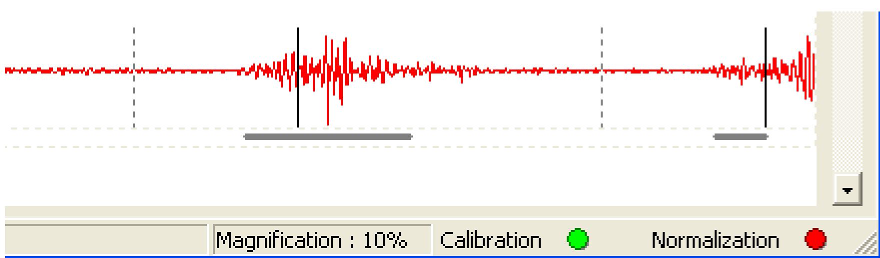


Figure 99: The calibration and normalization status is displayed on the Status bar

Unscale Data / Scale Data

By default, the ***EMG Analysis*** and ***EMG Graphing*** applications display the EMG data as scaled – that is, the software calculates and display the signals in terms of the

voltage levels at the recording ADC inputs, or alternatively at the electrode inputs, if the data scaling factors are known and the data has been calibrated. Thus the default is to display data within the maximum range of ±5V (or occasionally ±10V with some systems) or, if calibrated with the range of plus or minus a few millivolts.

Since the default is to display scaled data normalized to the maximum and minimum values within the file you should not see data displaying the maximum range unless clipping has occurred. Thus, seeing the maximum range values in the displayed data (i.e. a range of ±5V in most cases) is an excellent hint that the EMG system gains need to be lower for the affected channels.

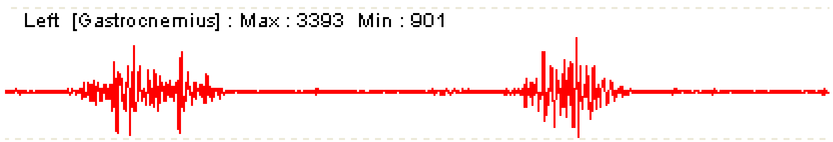


Figure 100 – Un-scaled data is displayed in terms of 'bits' of ADC resolution.

It is occasionally useful to view the EMG data without any scaling factors applied, in which case the data is displayed “un-scaled” in terms of recorded data bits. This can be very useful as it gives the electromyographer or laboratory engineer, an indication of the precise resolution of the recorded data. This menu option simply toggles the display between scaled (the default) and un-scaled modes.

Calibration

The ***EMG Analysis*** and ***EMG Graphing*** applications support two different calibration options – these are, calibration by data file, and calibration by gain switch settings. The Calibration File method assumes that the electromyographer has recorded a standard signal with a known level into each EMG channel, while the Gain Switch method assumes that the electromyographer knows the exact gain applied to each EMG channel.

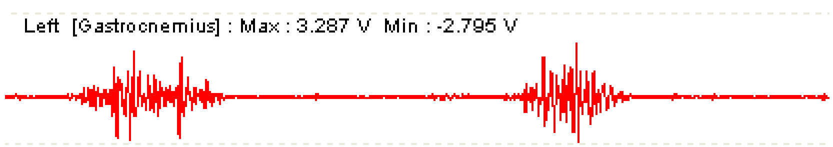


Figure 101 - Un-calibrated data is usually displayed in terms of Volts recorded.

In each case, the term “calibration” refers to a feature within the EMG Analysis and EMG Graphing applications that allows the displayed data to be plotted in terms of the signal level detected at the sensor inputs – generally the skin-surface unless indwelling (or fine wire) electrodes are being used in which case the intramuscular signal level is recorded.

By Calibration File

The calibration file method is especially useful when the EMG system has user adjustable gain controls.

Some EMG systems allow the electromyographer to create a calibration file that records a known calibration signal, in addition to the raw EMG data files. This calibration file can then be used to quantify the gains applied to each EMG channel and thus display the actual EMG levels.

The data in the active EMG file is calibrated from data recorded in the calibration file. This calibration file needs to be collected on the same system that the EMG data file was collected on, and is normally made at the end of a study, after the electrodes have been disconnected from the subject but before the gain controls have been changed.

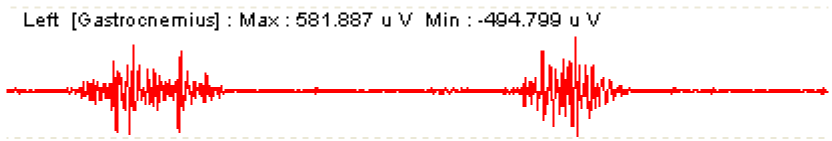


Figure 102- Calibrated data will display the signal in terms of uV or mV at the sensor input.

The ***EMG Analysis*** and ***EMG Graphing*** applications expect that the calibration signal will be a sine wave tone with a known RMS amplitude. This calibration signal will be measured and used to calibrate for the gain of each amplifier channel present in the EMG system. If active preamplifiers are used then the gain of the preamplifier must be known and is also factored into the calibration.

The calibration signal is a sine wave with a specific frequency and amplitude that is generated by, or applied to, the EMG system that is being used. For example the Motion Lab Systems ***MA-100*** systems generate an 87Hz sine wave signal at 65mV when the preamplifiers gain is taken into account.

The ***MA-300*** backpack generates an internal calibration signal that is a 78Hz sine wave of 8.8mV peak to peak applied to the backpack inputs. This is equivalent to a peak to peak signal level of 440uV at the input of a standard (x20 gain) preamplifier. The EMG software calibration uses RMS values so you enter 3.11mV for the calibration level for MA-300 systems calibrated using the internal signal.

The Calibration File option is available only when there is no normalization data applied to the file.

This command opens the Calibration File dialog box where you can choose the calibration file and set the amplitude and frequency of the signal as well as the preamplifier gain (generally around 320 for the MA-100 or 20 if you are using an MA-300 system). You can also Turn On and Turn Off the calibration data.

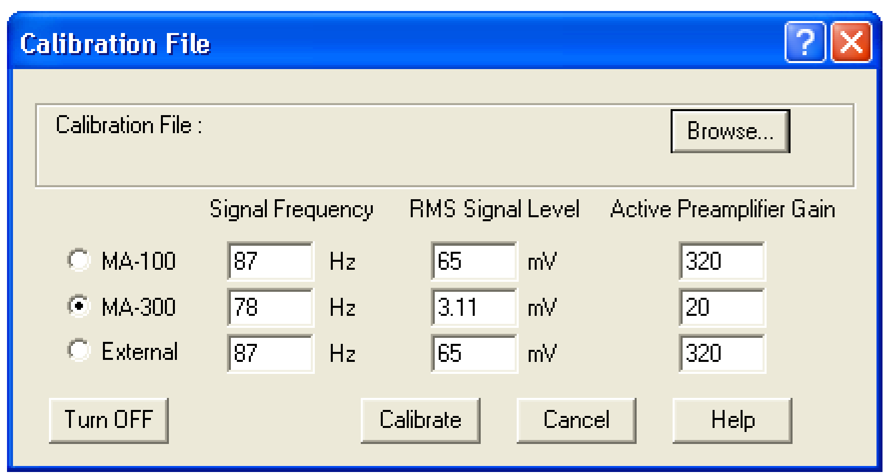


Figure 103 - The calibration dialog supports MA100, MA300 and external calibration signals

The Calibration File dialog box has the following controls – note than only the calibration signal for the selected system will be performed:

Calibration File - is the name of the calibration file that will be used to calibrate the data in the open file. You can use the browse button to search the directory structure to find the calibration file. The directory that is presented by default is the one in which the open data file is present – this is normally where you will expect to find the relevant calibration file.

Signal Frequency- allows you to enter the frequency of the calibration signal in Hz. MA-100 systems generate an 86Hz signal while MA-300 systems generate a 78Hz signal.

RMS Signal Level - allows you to enter the RMS value of the calibration signal in millivolts – this is 65mV for an MA-100 system and 3.11mV for an MA-300 system.

Active Preamplifier Gain – all Motion Lab Systems EMG systems use active preamplifiers that apply gain to the EMG signal at the skin surface. MA-100 systems used preamplifiers with a gain between 300 and 350 while MA-300 systems use preamplifiers with a gain of 20.

Calibrate - click on this button to calculate and apply the calibration data to the open file and then close the dialog box after the calibration is complete. The calculated calibration values for each channel are stored in the EMG:GAIN parameter when the C3D file is written. These values can be edited from the Edit:Channels dialog box if required.

Turn OFF- will turn off the calibration, returning the data to its original, un-calibrated values. The original calibration levels are preserved, allowing the file to be re-calibrated at a later data without referring to the original calibration data file.

Turn ON - this button will restore a file that has been calibrated but then had the calibration turned off.

The act of calibrating the EMG data creates a separate EMG:GAIN scale factor for each channel – this is a positive value if the calibration is enabled but is negated if the calibration has been disabled.

A value of minus one in the individual channel EMG:GAIN parameters implies that there is no calibration data present for the channel. If you save the EMG data file after calibration is performed, the calibration data will be saved and you will not have to choose this command the next time.

By Gain Switch

The Gain Switch calibration method is used when the EMG system used to record the signals has one or more fixed gain settings with known values – usually adjusted or preset, by switches.

The range of gain values associated with each switch setting are stored in the EMG.INI file and can be modified if you are not using an MA300 system.

For example, ***Motion Lab Systems*** MA-300 EMG systems have individual, switch selectable, gain controls for each EMG channel – each switch offering ten different gain settings. As a result, the output of the system is always calibrated if the gain switch settings are known - the EMG output levels from the MA-300 can be directly related to the EMG level at the pre-amplifier inputs. The ***EMG Analysis*** and ***EMG Graphing*** applications both support calibration of the EMG data by simply entering the gain switch settings in order to calibrate the data.

When calculating the overall system gain of an EMG channel, it is important to include all the sources of amplification in the instrumentation chain. For example, a standard MA-300 pre-amplifier has a gain of x20, thus with switch setting 2 (a system gain of x400), the EMG channel (with an MLS EMG pre-amplifier) accepts signals in the range of ± 1.25millivolts to produce a full-scale output of ±5.00 volts.

$$0.00125 \ * 20 * 400 \ = 10\,Volts$$

The ***EMG Analysis*** and ***EMG Graphing*** applications both store the results of their calibration calculations using the C3D file format parameters EMG:GAIN to keep the individual channel gain values separate from the standard ANALOG:SCALE values.

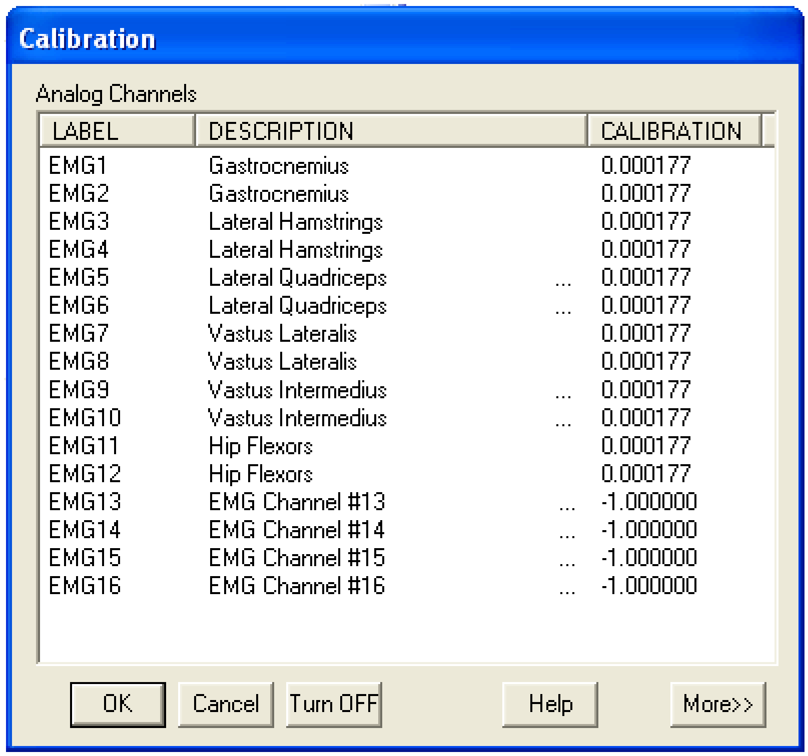


Figure 104: Calibration dialog box for MA-300

This command opens the Calibration dialog box. This dialog has the following controls:

Analog Channels - is a list box that shows you the EMG channels present in the file. You can double click on any of the calibration values and you will be given a drop box from where you can choose the value from 0-9 that was set on the backpack. This will cause the corresponding gain value to be applied to the channel.

More (or Less) - is a button that shows (or hides) the part of the dialog where you can set the gain value for each backpack setting.

Gain Values - is a list box that is displayed when the *More>* button has been selected and displays the backpack setting and the gain associated with it. You can double click on any gain value to edit it.

Restore Defaults – is a button that will restore the default gain values.

Turn OFF - this button to set the values of all the channels which have a value greater than 0, to a negative value. This will turn off the calibration. This button will be visible only if at least one channel has calibration turned on.

Turn ON - this button sets the values of all the channels which have a value less than 0 (but not equal to minus one), to its positive value. This will turn on the calibration. This button will be visible only if at least one channel has calibration turned off.

A value of minus one implies that there is no calibration data present in the channel. To turn off the calibration for a channel, its value is made negative and so is not used by the application. Only positive values are assumed to be valid gain values. Thus a valid value of 0.00045 would become -0.00045 when calibration is turned OFF.

Normalization

If Normalization is not selected then the EMG data will be displayed as absolute values, thus an EMG signal with a value of two millivolts will be twice as large as a signal of one millivolt.

If Normalization is enabled then one of two methods can be used – the EMG data can be normalized to the dynamic levels within the selected cycle(s) or the EMG data can be normalized to an external level (maximum voluntary contraction, resting EMG level etc) in a separate file.

This command is available only when the calibration data present in the file is not turned on

This is done by normalizing the data present in each channel to that collected in other files collected in a suitable manner. Each channel that needs to be normalized should be assigned a file from which the normalization data will be read. The Normalization process uses a large fixed window to reduce the effects of individual artifacts or spikes in the MVC signal. This means that the normalization will be repeatable in that it is independent of the user adjustable window size.

The MVC file selected is opened and the following operations are performed:

1. The window envelope is created for the MVC file using a fixed 150ms window.
2. The maximum value for the channel is then calculated.
3. The data values in the current EMG data are then normalized using this maximum value.
4. The normalization values that are calculated are stored in the EMG:Normalization parameter, so that the next time you open the file you don't have to go through the normalization process again.

The Normalization is a windowing process **-** in that we expect the normalization values to be applied to window enveloped EMG data but we're not strict about enforcing this which has the following consequences:

1. When analyzing enveloped data, the normalization values (%MMT) that we report will vary depending on the window size that you select to process the trial data.
2. When raw or rectified EMG data is graphed, the %MMT values will always be much larger than the enveloped data although they will be consistent **-** there's no window variable in the analysis to confuse matters.

This command opens the Normalization dialog box where you can choose the data. You can also Turn On and Turn Off the normalization data. These values are stored in the EMG: NORMALIZATION parameters. The application does not allow you to manually change the normalization values.

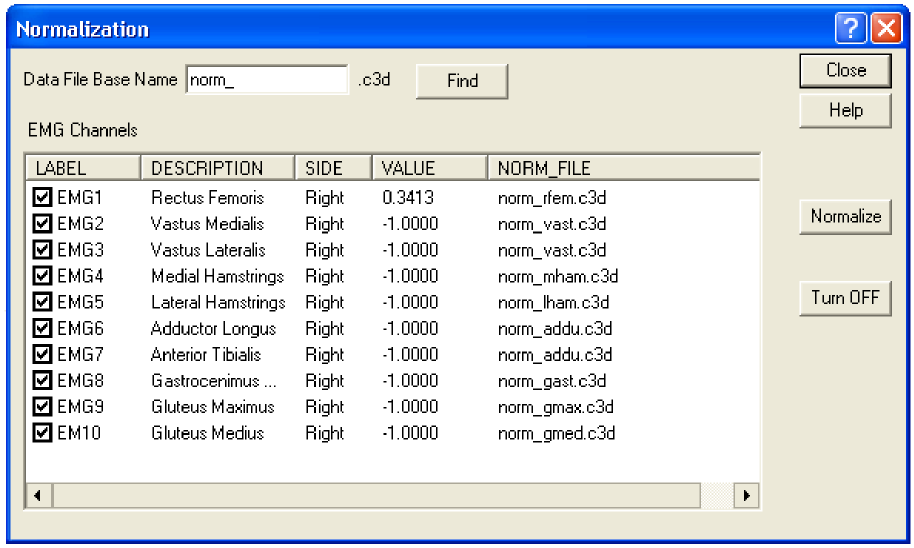


Figure 105 - The Normalization dialog box

The application looks for the normalization files in the same directory as that of the data file. The data files usually have a name to which the trial number is appended when data is collected. We shall call this the ***base name***. The application looks for all files in the directory that has the same base name as the data file and in addition has three characters appended to the base name.

This dialog box contains the following controls:

EMG Channels

This is a list control that has the Label, Description and Side of the channels of type EMG in the file. The fourth column shows you the normalization value of the channel. The fifth column shows the file that will be used to get the normalization value. When you double click on this, there will be a list box (***File List***) which shows you the normalization files found, either when the dialog opened or after you clicked the Find button. You can assign any file from the list for a channel. A file can be assigned to more than one channel.

Data File Base Name

This is the base name that the application uses by default. You can change this to suit your data capture methods. The extension that the application is going to look for is shown to the right of this control.

Find

Clicking on this button causes the application to look for files in the directory of the data file based on the base name is the Data File Base Name field. These files are used to populate the File List.

Normalize

Clicking on this button will find the normalization data for those channels that have a normalization file assigned to it. The dialog box will then close

Turn OFF

Click on this button to set the values of all the channels which have a value greater than zero, to a negative value. This will turn off the normalization for these channels. This button will be visible only if at least one channel has a normalization value greater than zero.

Turn ON

Click on this button to set the values of all the channels which have a value less than zero (but not equal to minus one), to its positive value. This will turn on the normalization for these channels. . This button will be visible only if at least one channel has a normalization value less than zero but not minus one.

A value of minus one implies that there is no normalization data present in the channel. To turn off the normalization for a channel, its value is made negative and so is not used by the application. Only positive values are assumed to be valid gain values. Thus a valid value of 0.035 would become -0.035 when normalization is turned OFF.

If you save the data file after normalization is performed, the normalization data will be saved and you will not have to choose this command the next time.

You can see the normalization status on the Status Bar in Figure 74.

Figure 106: Normalization state on Status Bar

The color of the Normalization light above can be one of the following:

- ***Gray***: Implies that there is no active file and the light is disabled.
- ***Red***: Implies that there is no normalization data in the active file. This means that the normalization value for all channels is minus one.
- ***Green***: This means that normalization data is present and is being used by the application. This means that channels have normalization greater than zero or minus one. At least one channel should have a value greater than zero.
- ***Yellow***: This means that normalization data is present, but is not being used by the application. This means that no channel has a value greater than zero. At least one channel should have a value less than zero that is not minus one.
- ***Yellow-Green***: This means that normalization data is present and is being used by the application for some channels and is not being used for others. At least one channel should have a value greater than zero and at least one channel should have a value less than zero that is not minus one.

Analyze menu

The Analyze menu offers all the commands needed to carry out various analysis operations provided by the ***EMG Analysis*** and ***EMG Graphing*** applications on the collected data. As a result, all the commands in this menu require that a data file be opened before they can be executed. Furthermore, all of the analysis operations require that at least a pair of Foot-Contact events have been created on one of both sides to define sections of the EMG data file for the analysis operations.

Figure 107 – The EMG Analysis menu (left) versus the EMG Graphing menu (right).

The options that are displayed on the Analysis menu will depend on which version of the application is registered – the ***EMG Analysis*** application enables all the analysis options while the ***EMG Graphing*** application enables only the basic features required for basic EMG data graphing. Please contact Motion Lab Systems, Inc., if you would like to upgrade a copy of the ***EMG Graphing*** application to the full ***EMG Analysis*** application.

Events

The ***EMG analysis*** and ***EMG Graphing*** applications are designed primarily to analyze electromyographic signals from periodic activities – gait is a typical example.

When a C3D file is opened, the application looks to see if the EVENT-TIMES parameter is present. If this parameter is present, it reads the data from it. If the parameter is not present, the application reads the header of the file, where event information can be stored.

Foot Switches

This command can be used to create cycles using any foot switch data that may be present in the data file.

You can adjust the levels at which the ON and OFF transitions take place using the Events: Foot Switch Levels command on the Edit menu.

For this command to work, it is essential that there is a channel that has been marked as foot switch channel on each side. This can be done using the Channels command on the Edit menu.

Force Plates

The force plate data present in the file can be used to analyze the cycles of data present. This requires that force plate data be present in the file and also that 3D data be collected. At present only the C3D files satisfies both these requirements. The application gets information about the FZ (n) channels from the FORCE_PLATFORM: CHANNELS parameter and the number of force plates from the FORCE_PLATFORM:USED parameter. Also the ANKLE and TOE markers need to be present.

When this method is used, sometime the ANKLE or TOE markers could be just at the edge of the force plates. You can choose to artificially extend the edges of the force plate by a few millimeters. This can be done from the *Channel Options* Property page that can be accessed using the *Defaults* command on the *View* menu.

Full Trial

This command causes the entire trial to be displayed.

Each channel is shown in its own rectangular box. You can select a channel by clicking inside the box. If you click on the Event Bar, you will be provided with a cursor that you can move around by dragging it.

You can control the way in which the data is viewed by:

- You can change the vertical size of each graph from the Graph Defaults Property page that can be accessed using the Defaults command in the View menu.
- You can change the way in which the labeling is done from the Graph Defaults Property page that can be accessed using the Defaults command in the View menu.
- You can view scaled or un-scaled data using the Scale (or Unscale) Data command in the View menu. Calibration values and normalization values are all applied only to scaled data.
- Left and right side EMG channels are drawn with their respective colors which can be set using the Graph Defaults Property page (See page 82) that can be accessed using the Defaults command in the View menu.

Raw EMG

The display of raw EMG within an event defined period is supported by both versions of the EMG Analysis and the EMG Graphing applications.

The Raw EMG function allows the electromyographer to view the raw EMG from a single gait cycle. Visual inspection of the raw EMG signal is a useful way of examining muscle activity as it changes with time as well as providing a way of assessing the quality of the signal and the reliability of any subsequent analysis functions. In addition, correlation of EMG activity with other biomechanical variables helps the electromyographer in the understanding of normal muscle function as well as special motor functions in pathologies.

When a trial consists of multiple periods (or gait cycles) of EMG data then the electromyographer can select which of the available EMG cycles is to be displayed using menu that appears when the right mouse button is pressed.

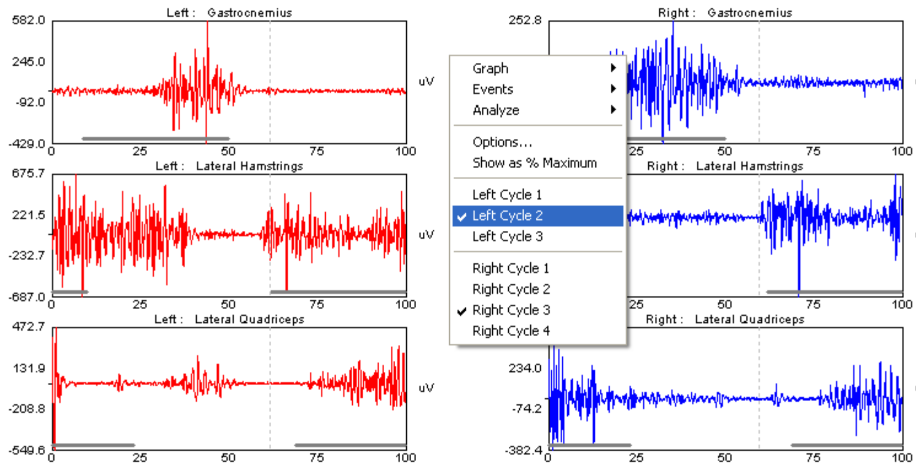


Figure 108 - Different gait cycles can be selected via the right click menu.

The ***EMG Analysis*** and ***EMG Graphing*** applications both include a number of databases that contain normal EMG activity timing information. This can be plotted at the bottom of each display to indicate the range over which the muscle is supposed to be active **-** for this to take place you must:

3. Ensure that the correct section of the database has been chosen in the *Edit:Normal EMG Data* dialog box (accessed from the Edit menu (See Page 60).
4. Identify the EMG channel with a description that corresponding exactly to the appropriate channel described in the normal database (accessed from the *Edit:Channels…* menu).

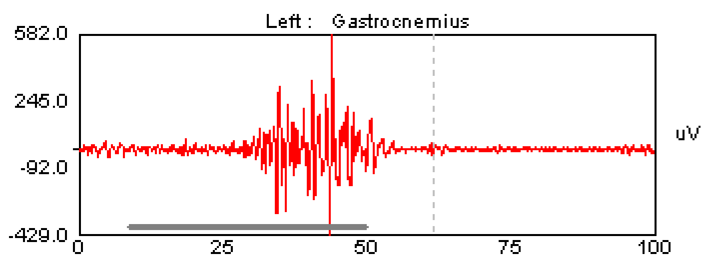


Figure 109 - Raw EMG with normal activity shown.

Each EMG channel displayed by the Raw EMG function can be scaled to indicate any one of the following ranges:

Uncalibrated – resulting in the EMG data being displayed in terms of some arbitrary device measurement units. Generally, this will indicate EMG levels in terms of the signal measured (in Volts) at the input of the data collection system (ADC) but other scaling are possible.

Calibrated at sensor input – generally in uV or mV indicating the maximum and minimum values recorded at the sensor input (skin surface or intra-muscular levels) during the plotted gait cycle.

MVC – resulting in EMG data being displayed as maximum/minimum values relative to the Maximum Voluntary Contraction signal recorded for the channel.

Normalized – resulting in the EMG data being displayed as maximum and minimum values of 100% over the cycle.

Relative – resulting in all the EMG channels being displayed to a single scale – this allows the differences in levels between one muscle and another to be evaluated.

Full Wave Rectified EMG

The Full Wave Rectified function mathematically processes the Raw EMG signal to invert all signal components that have a negative value. This results in an output that contains only positive signal components.

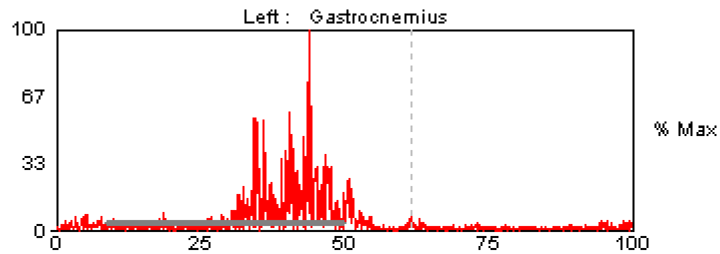


Figure 110 - Full Wave Rectified EMG

Moving Average

Moving Average is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The window envelope is achieved by averaging the absolute value of the raw EMG over the time of the window. The size of the window can be varied. The resulting plots are obtained by averaging the gait cycles that are used for the processing. All the options that are available can be found in the Window Envelope Page accessed using the Defaults command (See page 79).

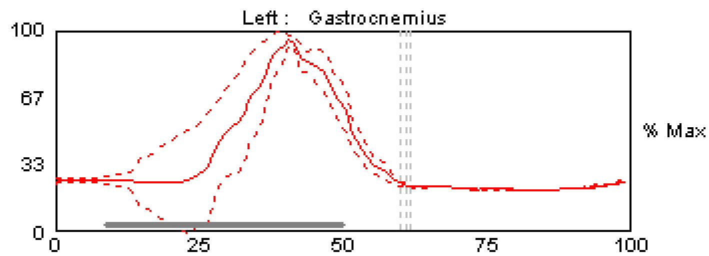


Figure 111 - Moving Average with normal activity bar shown.

A common digital moving average is realized by a “window” which calculates the mean of the detected EMG over the period of the window. As the window moves forward in time a new average is calculated. It can be expressed as:

$$\text{WindowAverage} = \frac{1}{T}\int_{t-\frac{T}{2}}^{t+\frac{T}{2}} |\text{EMG}|\,dt$$

Its value is in volts and it is required to specify the window width T. In this application the average is calculated for the middle of the window because it does not introduce a lag in the output. If the moving average is calculated only for the past history then it introduces a phase lag that increases with time T.

The Window Average is calculated by taking a window of size N ms (or the size chosen by you) and averaging the rectified signal in that window.

An ensemble average is calculated as (assuming a time of N ms is equal to T points):

$$\text{EMG\_ENV}(x) = \frac{1}{T}\sum_{i=x-\frac{T}{2}}^{i=x+\frac{T}{2}} \text{EMG}_i$$

The cycles to be used in this average can be selected using the Select Cycles command from the Edit menu (See page 67).

Linear Envelope

Linear Envelope is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The filtered envelope is obtained by passing the rectified raw EMG through a low pass Butterworth filter. The cut off frequency of this filter can be changed. Also a second order Butterworth filter introduces a phase lag at the output as compared to the input. To eliminate the phase lag, the signal can be filtered again in the reverse direction, which effectively converts the filter to a fourth order filter.

All the options that are available can be found in the Filter Envelope Page accessed using the Defaults command from the View menu (See page 79).

Filtering the full wave rectified EMG signal with a low pass filter yields a linear envelope. This is similar to a moving average because it follows the trend or the envelope of the EMG and also resembles the shape of the tension curve. The filter used should have a cut off between 3 Hz and 6 Hz and should be a second order type.

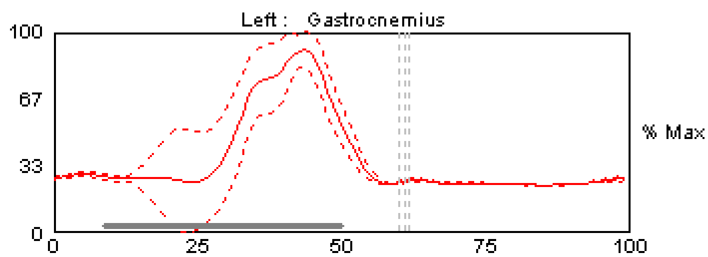


Figure 112 - Linear Envelope with normal activity shown.

The frequency of human movement lies below 10 Hz, so any signal thought to be representative of muscle tension should not contain harmonics above 10 Hz. The linear envelope is a good representation of the way the EMG activity changes with time over the period of the contraction. A linear envelope can be used to provide an envelope that represents a profile of the myoelectric activity of the muscle over time.

The Butterworth filter is implemented as,

$X_f(nT) = a_0X(nT)+a_1X(nT-T)+a_2X(nT-2T)+b_1X_f(nT-T)+b_2X_f(nT-2T)$

where,

X_f are the filtered output points

X are the unfiltered data points

nT is the nth sample

nT-T is the $(n-1)^{th}$ sample

nT-2T is the $(n-2)^{th}$ sample

$a_0..,b_2..$ are the filter coordinates calculated as below,

$\omega c = \tan(\pi f_c/f_s)$

where,

f_c is the cut off frequency

f_s is the sampling frequency

$k_1 = \sqrt{2}\, \omega_c$

$k2 = \omega_c^2$

$a_0 = k_2/(1+k_1+k_2)$

$a_1 = 2a_0$

$a_2 = a_0$

$k_3 = 2a_0/k_2$

$b_1 = -2a_0 + k_3$

$b_2 = 1 - 2a_0 - k_3$

The filtered output is a weighted version of the immediate and past raw data plus a weighted contribution of past filtered output.

As well as attenuating the signal, there is a phase shift of the output signal relative to the input. For the second order filter shown above, there is a 90° phase lag at the cut off frequency. This causes phase distortion to the higher harmonics in the band pass region.

To cancel out this phase lag, the once filtered data is filtered again, but in the reverse direction of time. This introduces an equal and opposite phase lead so that the net phase shift is zero. Also the cut off of the filter is twice as sharp as that achieved with single filtering. In effect this filtering creates a fourth order zero phase shift filter.

An ensemble average is calculated as (assuming a time of N ms is equal to T points):

$$\mathrm{EMG\_ENV}(x) = \frac{1}{T} \sum_{i=x-\frac{T}{2}}^{i=x+\frac{T}{2}} \mathrm{EMG}_i$$

The cycles to be used in this average can be selected using the Select Cycles command from the Edit menu (See page 67).

RMS Analysis

RMS Analysis is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The RMS Analysis function performs a more sophisticated form of averaging than either the Linear Envelope or Moving Average methods and is generally considered to produce more reliable results with a wide range of data. The options available with this analysis enable the user to completely control the signal processing so that the results can be duplicated in Research Environments.

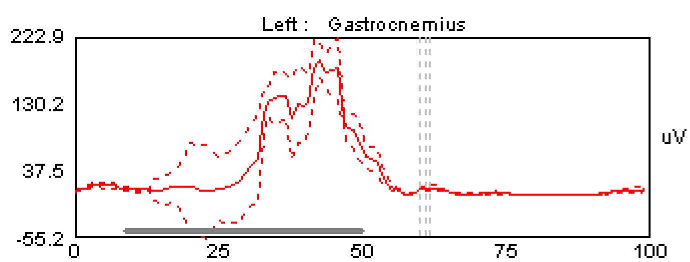


Figure 113 - RMS Analysis with normal activity shown

The raw EMG data is initially processed through a dual pass, zero delay, high pass filter, normally set to remove frequencies below 5Hz to ensure that there is no DC offset in the data. The precise filter value may be set by the user. The filtered data values are then mathematically squared, generating EMG data values that contains only positive values – the mean value of this data stream is then calculated over a user selectable interval and the square root of the resulting values is displayed.

IFA (Intensity Filtered Average)

Intensity Filtered Average is an EMG Analysis function and is not available in the Basic Graphing version of the software.

This analysis is described in the paper *Computer Algorithms to Characterize Individual Subject EMG Profiles During Gait* published in 1992 by Ross Bogey, Lee Barnes, and Jacquelin Perry, MD. The Intensity Filtered Average (or IFA) is found by first creating an envelope of the signal for the selected cycle by using a 12ms moving window (the IFA options allow this window length to be varied). The envelope is then processed to remove all EMG data values from the envelope that are less than user selected percentage (nominally 5%) of the associated maximal manual muscle test (MMT) for the muscle. 100% MMT is defined as the 20ms interval with the greatest mean intensity during processing of the maximal manual muscle test data using the same window defined for the trial data. Each muscle will require an associated maximal manual muscle test data collection in order to perform IFA analysis.

The resulting EMG data file is then processed to exclude low intensity and short duration activity from the trial data. Low intensity EMG activity is defined as any portion of the trial data that is less than a preset (nominally 5% but adjustable via an optional setting) proportion of the MMT trial. Short duration activity is defined as a burst of activity that starts and stops with a period of less than 5% of the current gait cycle and is separated from another period of EMG by more than 5% of the gait cycle. As a result, the IFA algorithm may not be appropriate for EMG activity that is not gait cycle related.

The values are reported in terms of % of Maximum Manual Test (MMT). For this command to be enabled, it is essential that the channels you are interested in have been normalized (See Page 107).

Threshold Detection

Threshold Detection is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The *Threshold Detection* function reads the output of either the *Linear Envelope* or the *Moving Average* functions (either function can be selected) and normalizes the result. The electromyographer can set values (in terms of percentage of maximum EMG level from either function) for up to ten thresholds, which will result in a signal output if the selected threshold value is exceeded. Each threshold level is expressed as a level from 1 to 100% of the selected envelope or average function.

The output of the Threshold Detection function is a series of blocks that appears similar to a histogram and can be quite useful in providing a quick analysis of the EMG signal if you simply need to determine periods of muscle activity. Setting the Threshold Detection to use two levels produces an output that simple indicated EMG activity in terms of ON or OFF and can, if the EMG normal activity bars are displayed, result in a clear comparison between subject and “normal” muscle activity. This comparison can be enhanced if additional levels of activity are detected by selecting three or four different levels to produce a stepped waveform that more closely represents the detected level of muscle activity.

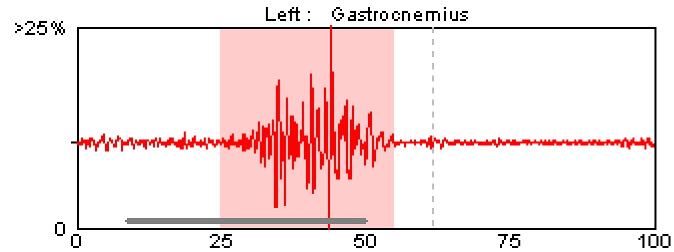


Figure 114 - Threshold Analysis with raw data and normal activity shown.

One common complaint with this type of EMG processing is that it can be unreliable if the subject EMG signal is noisy or otherwise corrupted – the Threshold Detection function addresses this problem by allowing the raw EMG data to be displayed as an overlay on the Threshold Detector graphs. This enables the quality of the data and the choice of threshold levels to be assessed as the data is analyzed.

Zero Crossing

Zero Crossing is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The Zero Crossing function measures and displays the number of times that the raw EMG signal crosses a user define value related to the zero axis of the raw EMG data. A true "zero crossing" function would generate an output every time that the EMG signal crossed zero which, unless the baseline was unusually quiet, or a baseline noise reduction algorithm is used in pre-processing the data, will result in almost continuous signal output. As a result, the ***EMG Analysis*** software allows the user to select a degree of hysteresis in the Zero Crossing algorithm – typically hysteresis values of 10 to 20% of the maximum EMG signal level will produce useful results.

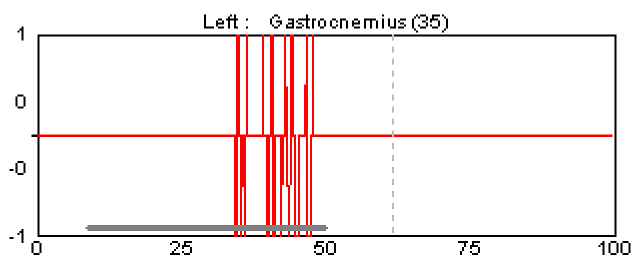


Figure 115 - Zero Crossing Analysis with normal activity shown

The output from the Zero Crossing function is a series of positive and negative values – a positive output is generated when the EMG signal level is greater (more positive) then the positive hysteresis level, while a negative output indicates that the raw EMG signal is less (more negative) then the negative hysteresis level. The number of crossings over any given period of time, for a selected hysteresis level, is directly proportional to the level of EMG activity.

Integrate over Time

Integrate over Time is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The *Integration over Time* function performs a mathematical integration of the *Full Wave Rectified* EMG signal over a user defined period of time measured in milliseconds and then reset to zero resulting in an output measured in Volts per Second. Typically, reset periods of 50 to 200 milliseconds are used although the ***EMG Analysis*** program allows a wider range of time to be specified.

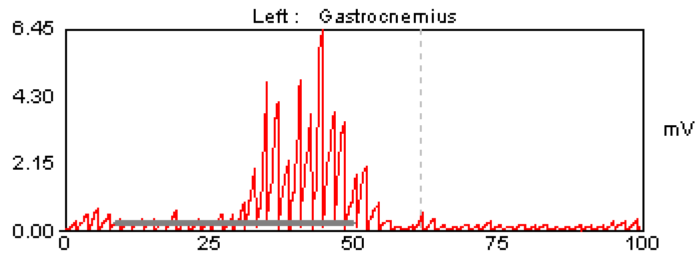


Figure 116 - Integrate over Time with normal activity shown.

The resulting output from this analysis function is a series of ramped waveforms that reset to zero at the selected interval – the height, and area under the curve, of each interval translate directly to the EMG signal level during the integration period.

Integrate and Reset

Integrate and Reset is an EMG Analysis function and is not available in the Basic Graphing version of the software.

The *Integrate and Reset* function performs a mathematical integration of the *Full Wave Rectified* EMG signal until a preset voltage level is reached – once the user defined reset voltage is reached, the function is reset to zero and the integration function is restarted. Like the *Integrate over Time* function, this produces an output that is measured in Volts per second.

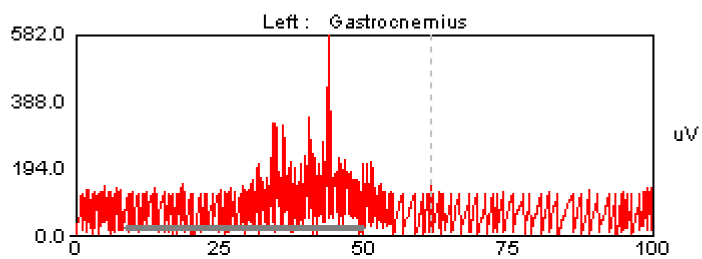


Figure 117 - Integrate and Reset with normal data shown.

Like the *Integrate over Time* function, the output from this analysis function is a series of ramped waveforms that reset to zero – except that in this case, the reset occurs not at a set period of time but instead, when a preset voltage level is reached. Thus the function relates the length of the ramped waveform to the level of EMG activity – short waves indicate higher levels of activity while longer ramps indicate lower levels of activity.

EMG Power Spectrum

Power Spectrum is an EMG Analysis function and is not available in the Basic Graphing version of the software.

This command results in the plotting of the amplitude spectrum of the chosen muscles against their frequency. The y-axis of the plot is the amplitude in volts and the x-axis is the frequency in Hz. The frequency range is from zero to the value indicated on the y-axis. The user has the option of calculating this over the entire gait cycle (or defined period), or else calculating it for only portions of the cycle that exceed a specified level. An additional option enabled the users to calculate the power spectrum for all portions of the cycle that fall below the specified level and subtracting this from the reported power spectrum to remove background noise from the results.

This command causes the Power Spectrum dialog box to open, where you can make the following selections:

- The channels for which the power spectrum needs to be analyzed.

- The start and end of the data in terms of the gait cycle.

The frequency up to which the data needs to be plotted. The maximum frequency that can be plotted is half the sampling frequency (remember the Nyquist criteria).

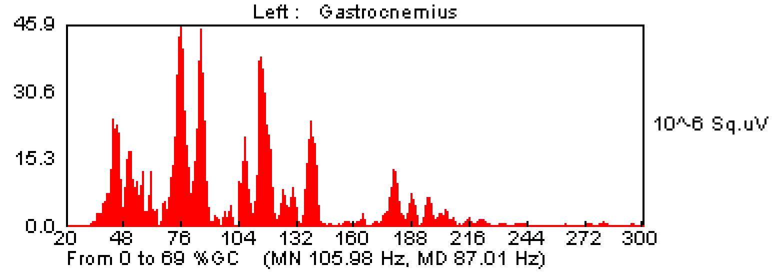


Figure 118 - Power Spectrum Analysis

The FFT routine accepts the data array consisting of n points with the complex part of each sample point set to zero. The data array is then padded with zeroes so that the total number of points after padding N, is an integer power of 2. It is then sent to the FFT routine, which returns N complex points corresponding to frequencies ranging from $-f_s/2$ to $f_s/2$, where f_s is the sampling frequency, with the resolution being $1/N\Delta$.

The maximum frequency that is plotted is the lesser of half the sampling frequency (remember the Nyquist criteria) and half the number of points N (since that is the number of positive frequencies returned by the Fourier routine).

Amplitude Distribution

Amplitude Distribution is an EMG Analysis function and is not available in the Basic Graphing version of the software.

This command results in the plotting of the power spectrum of the chosen muscles against their frequency. The y-axis of the plot is the amplitude in volts^2 and the x-axis is the frequency in Hz. The frequency range is from zero to the value indicated on the y-axis. The command results in the plotting of the power spectrum of the chosen muscles against their frequency. The y axis of the plot is the power in volts^2 and the x axis is the frequency in Hz. The frequency range is from zero to the value indicated on the y-axis.

The power spectrum of a function can be obtained by taking the modulus square of the DFT of the function over a finite stretch. In general there is some relation of proportionality between a measure of the squared amplitude of the function and a measure of the Power Spectral density of the function.

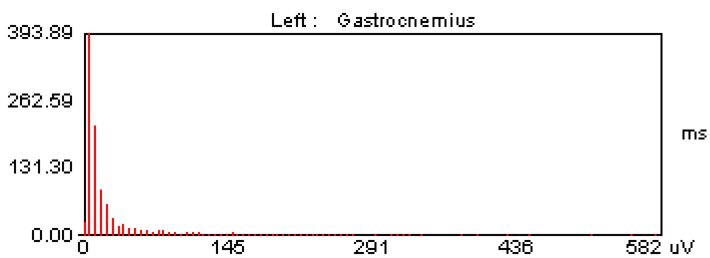


Figure 119 - Amplitude Distribution analysis

There are several different conventions for describing the normalization in each domain. The power spectral density can be defined for:

- discrete positive, zero and negative frequencies, and its sum over these is the function mean squared amplitude.

- zero and discrete positive frequencies only, and its sum over these is the function mean squared amplitude.
- the Nyquist interval from $-f_c$ to f_c, and its integral over this range is the function mean squared amplitude.
- defined from 0 to f_c, and its integral over this range is the function mean squared amplitude.

It never makes sense to integrate the PSD of a sampled function outside the Nyquist interval since, according to the sampling theorem, power there is aliased into the Nyquist interval. The method of power spectrum estimation is called the periodogram. The periodogram is defined as,

$$P(f_k) = \left(\frac{1}{N^2}\right)\left[|C_k|^2 + |C_{n-k}|^2\right]$$

for k=0 .. N/2

The amplitude spectrum of the signal is obtained in exactly the same manner as the one explained above. The power of the signal at each point is then found by using the above formula after the amplitude spectrum has been found. The total power in the sample space is then computed. The mean power frequency (mpf) is calculated as,

$$mpf = \frac{1}{TotalPower}\sum_{k=0}^{N/2} P_k f_k$$

Cocontraction

Cocontraction is an EMG Analysis function and is not available in the Basic Graphing version of the software.

This command allows you to view the correlation (or lack of correlation) between pairs of muscles and this is plotted up to the desired frequency. The minimum and maximum values possible for the correlation are -1 and +1 respectively. This command opens the Correlation dialog box shown in where you can select the muscle pairs that you want to correlate.

The correlation of two functions is defined by

$$Corr(g,h) = \int_{-\infty}^{+\infty} g(t+t)h(t)dt$$

The correlation is a function of t, which is called the lag. It therefore lies in the time domain and is one member of the transform pair

$$Corr(g,h) \Leftrightarrow G(f)H*(f)$$

The correlation of the function with itself is called autocorrelation.

The autocorrelation of the EMG signal will be one at time t=0. As time t increases, the value of the correlation decreases.

The correlation between two different muscles is called cross correlation. The correlation of two different muscles will be large at some value of t if the first function (g) is a close copy of (h) but lags in time by t., i.e., if the first function is shifted to the right of the second. Likewise the correlation will be large for a negative value of t if the first function leads the second, i.e., is shifted to the left of the second. The relation that holds when the two functions are interchanged is,

$$Corr(g,h)(t) = Corr(g,h)(-t)$$

The correlation can be computed very easily using the FFT. First FFT the two data sets and multiply one resulting transform by the complex conjugate of the other and inverse transform the product. The result will be a complex vector of length N (where N is the number of sample points) with all the imaginary parts set to zero, since the original data sets were both real. The components to the resultant vector will give the correlation at different lags. For a correlation for lags as large at K, there needs to be a buffer zone of K zeroes at the end of both data sets. The extreme case is padding the data sets with N zeroes, which is what is done here.

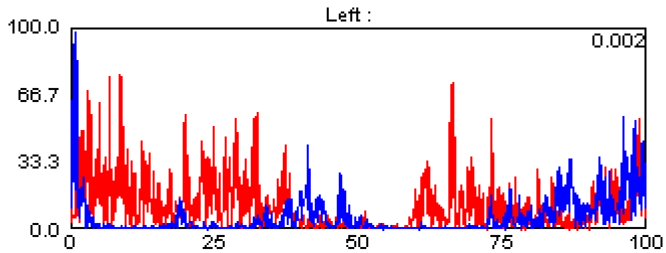


Figure 120 - Cocontraction Analysis

The data sets are sent to a function that combines the two into one array. One of the functions occupies the real part and the other occupies the imaginary part. Since the input data is real, it satisfies the property,

$$FN - n = (Fn)*$$

where the asterisk denotes complex conjugation.

By the same token, the DFT of a purely imaginary set of data has the opposite symmetry,

$$GN - n = -(Gn)*$$

Therefore, the DFT of two real functions is found by packing the two data arrays into the real and imaginary part of a complex input array, which is sent to the same Fourier routine, described earlier. The resulting transform is then unpacked by using the symmetries shown above.

The auto correlation is normalized by the value at t=0. This ensures that the maximum value will be 1.

The cross correlation is normalized by,

$$\sqrt{AutoCorr(g,g)(0) * AutoCorr(h,h)(0)}$$

Aliasing

Aliasing Reporting is an EMG Analysis function and is not available in the Basic Graphing version of the software.

Aliasing is a sampling problem in any data acquisition system. It can cause erroneous results and occurs whenever the incoming EMG signal contains frequency components that are at, or higher, than half the analog sampling rate. If the incoming EMG is not filtered to remove these frequencies, they will show up as aliases or false lower frequency components is the recorded EMG signal that cannot be distinguished from valid sampled data. The alias signals are actually at a higher frequency, but are “folded back” by the sampling process to create false low frequency signals below half the sampling rate.

For example, with a sampling rate of 1,000 Hz, any EMG components in the signal that are above 500 Hz will be aliased to appear as EMG signals in the range of DC to 500 Hz (the actual range of EMG signals that the sampling system is capable of

recording) thus leaving errors in different locations throughout your data each time you use an A/D converter.

While it may appear that the aliasing problem can be eliminated by sampling the EMG signal at a very high rate, such over-sampling of data requires faster A/D conversion - often at rate that are not supported by many analog recording systems. It also produces larger files that contain more data to process and does not guarantee that aliasing will not be a problem.

One, often neglected, source of aliasing is the presence of noise in the EMG signal. While you may be confident that your EMG spectrum is 10Hz to 400Hz (for example) suggesting that sampling at 1000Hz is fast enough to avoid aliasing, the presence of noise in the signal (perhaps introduced within the electronics amplification) at low levels above 500Hz will guarantee that aliasing will occur.

Avoiding Aliasing

The only practical way of avoiding the possibility of aliasing errors is to filter the bandwidth of the sampled EMG signal so that the signal presented to the A/D sampling system does not contain any frequency components above one-half of the A/D sample rate. This is easily done with a good quality low-pass or anti-alias filter on each A/D input channel prior to the A/D converter. Low-pass filtering must always be done before the signal is sampled as there is no way to remove the aliasing errors from the original signal once it has been digitized.

As dictated by the Nyquist theory, the EMG signal needs to sampled by the A/D converter at a rate that is, at a minimum, twice as fast as the highest frequency component of the EMG signal. This rule applies to any sampling system and the filter point is often referred to as the Nyquist frequency and all frequency components above this point must be removed before sampling.

A perfect a low-pass filter would pass all EMG signal components with frequencies from DC to the filter cutoff frequency while completely suppressing all frequencies above the filter point. Unfortunately it is not possible to build a perfect filter with an exact cut off point and all analog filters pass some frequencies above the cut off point. This is called the roll-off or attenuation slope where small amounts of signals are still present, although at a much lower level than the original. These attenuation slopes are normally greater than 40-50 dB/octave and attenuate the frequency components in the original signal that are greater than the cut-off point by 80 to 100 dB.

It is important to realize that high-frequency components in any signal presented to an A/D system can result from a number of different sources that are unrelated to the EMG signal from the muscle. High frequency signals above the Nyquist point may come from the inherent noise of the EMG system itself, and from noise or interference, broadcasting stations, and mechanical vibrations. High-frequency components also are inherent in any sharp transitions of the measured signal such as may occur when equipment subject to any unexpected vibration (e.g. dropped etc). Low-pass filters generally can eliminate alias errors from the recorded EMG signal as long as the filters precede the A/D converter. A low-pass filter serves as an important element of any data acquisition system in which the accuracy of the acquired data is essential.

This command displays the power spectrum of the EMG Channels in the trial within the frequency limits set by you in the General Page (See Page 79).

Listen to Channel

The ability to replay the

This command allows you to listen to the data from the selected channel. You must

EMG signal to listen to it is an EMG Analysis function and is not available in the Basic Graphing software.

have suitable audio equipment for this command to work. The data is up sampled to 8000 Hz with 16 bit resolution and then played back. You have to select a channel in the trial view before you can select this command. This command is also available from the right click menu in the trial view.

You can stop the playback by selecting another channel. The playback will also stop if you choose any command on the Analyze menu or if you change the active file. Note that since the EMG signal is primarily composed of low frequencies (in normal audio terms) you will only hear a significant audio signal if you have high quality loudspeakers with a god low frequency response. In practical terms this means that most laptop computers will produce very little sound – a set of PC Gaming speakers with a power sub-woofer are recommended if you plan to use this facility.

Save Channel to Wav

The ability to create .wav files is an EMG Analysis function and is not available in the Basic Graphing software.

This command will export the selected EMG channel to a .wav formatted audio file. This allows users to create EMG samples that can be replayed or edited with standard audio editing applications for demonstration. In addition, the .wav format is supported by many sophisticated third-party spectral and wavelet analysis applications.

Export:C3D File

The ability to export data to C3D files is an EMG Analysis function and is not available in the Basic Graphing software.

This command will process the EMG data using one or more of the options selected in the dialog box and export the results to the C3D file in the form of additional analog channels. This option processes the entire trial from beginning to end and creates analog channels that store a processed analog sample for each raw analog sample. The resulting output is not time-normalized.

Each of the output channels will be processed according to the options selected in the individual EMG Analysis processes.

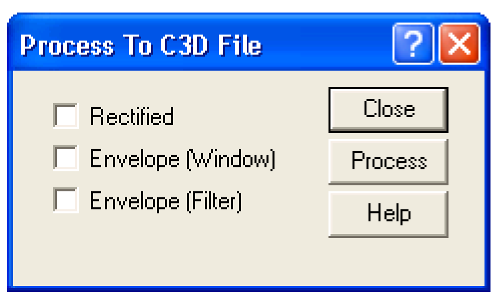


Figure 121 - Three C3D output options are available in EMG Analysis only.

Export:GCD File

The ability to export data to the GCD format is supported by both EMG Analysis and the EMG Graphing software.

This command can be used to output the data to the GCD file. This command opens the Process dialog box (Figure 90) that can be used to select the data that will be written to the GCD filename selected. If an existing GCD filename is entered here then the GCD calculations are appended to the file – if the file does not exist then it will be created.

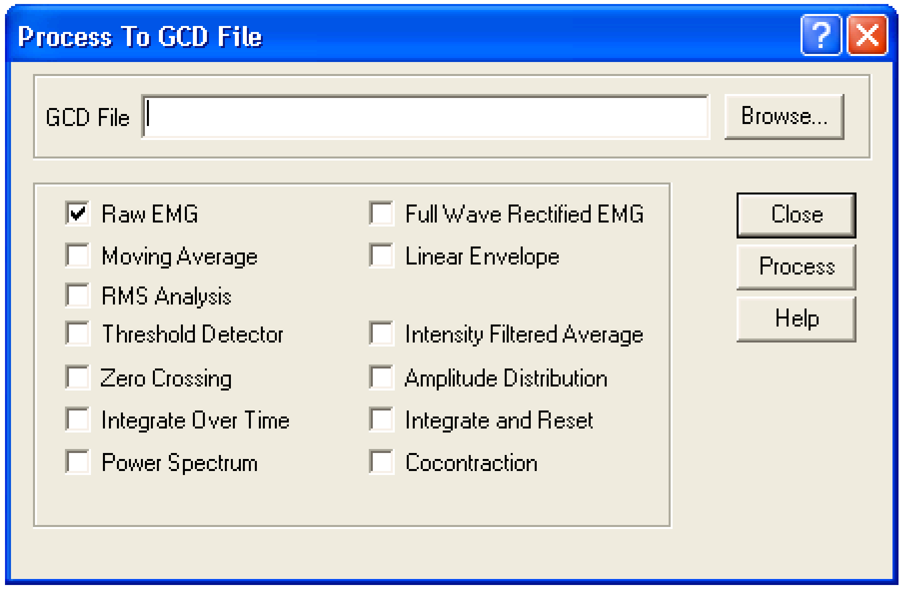


Figure 122: Process dialog box

This dialog box has the following controls that allow you to select the GCD file:

GCD File

This is the name of the GCD file to which data will be exported.

Browse

Clicking on this button allows you to browse the directory structure and choose an already existing GCD file.

There are also check boxes in the dialog that allows you to choose the process to output. These are:

- ***Raw*** **-** This exports the raw EMG data from the selected cycles.
- ***Full Wave Rectified EMG*** **–** This exports the raw EMG after full wave rectification.
- ***Moving Average*** - This exports the linear envelope created using a moving window.
- ***Linear Envelope*** **-** This exports the linear envelope created using a low pass Butterworth filter.
- ***RMS Analysis*** **–** The exports data created using a specific Root Mean Square algorithm.
- ***Threshold Detector*** **-** This exports level detector data indicating when the EMG signal levels exceed a specific level.
- ***Intensity Filtered Average*** **-** This exports the Intensity filtered average of the selected channels.
- ***Zero Crossing*** - This exports information about the number of zero crossings within the selected period.
- ***Amplitude Distribution*** **-** This exports the amplitude spectrum of the selected channels.
- ***Integrate over time*** **–** This exports data from the results of the Integration process.

- ***Integrate and Reset –*** This exports data from the results of the integration process for the specified reset period.
- ***Power Spectrum -*** This exports the power spectrum of the selected channels.
- ***Cocontraction -*** This performs the correlation between selected muscle pairs on the same side and exports this data.

The following buttons are present in the dialog box:

Process

Clicking on this button causes all the processes that have been checked to be output to the selected GCD file.

Close

This button closes the dialog box – note that closing the dialog box does not, by itself write any data to the GCD file – only the Process button create or appends GCD data to the specified file.

GCD Variables

A number of GCD variables are always written to the GCD file, regardless of the GCD process(s) selected. These variables are:

```
!SideStanceTime
!SideStancePercent
!SideSwingTime
!SideSwingPercent
!SideInitialDoubleStanceTime
!SideInitialDoubleStancePercent
!SideFinalDoubleStanceTime
!SideFinalDoubleStancePercent
!SideSingleStanceTime
!SideSingleStancePercent
```

In addition to this, the following data can be output to the GCD file based on your selection in the dialog box:

Raw Data

The raw data from the selected cycle can be output to the GCD file. All the frames of data that lie within the cycle are written to the file. The label of each section is generated as:

```
!SideDescriptionRaw
```

Linear Envelope using a low pass filter

The envelope can be generated by using a low pass Butterworth filter. In this case the number of points that will be output can be selected by you. If the standard deviation is present, it is also exported.

The data that is output to the GCD file is:

`!FilterCutOffFreq` - This is the cut off frequency of the low pass filter.

`!FilterPasses` - This is the number of passes of the filter which can be 1 or 2.

`!SideDescriptionFilter` - This is the actual data for each channel.

Linear Envelope using a moving window

The envelope can be generated by using a moving window of a specified time duration. In this case the number of points that will be output can also be selected by you. If the standard deviation is present, it is also exported.

The data that is output to the GCD file is:

`!EnvelopeWindowSize` - This is the size of the moving window in seconds.

`!SideDescriptionWindow` - This is the actual data for each channel.

Intensity Filtered Average

The intensity filtered average is obtained by getting the envelope using a moving window or a normalized EMG channel and then setting those values which are below a certain threshold to zero. Spikes of the envelope are also removed by making sure that they exist for at least 5% of the cycle.

The data that is output to the GCD file is:

`!IfaWindowSize` - This is the size of the moving window in seconds.

`!IfaThreshold` - This is the value below which the envelope data is set to zero, expressed as a percentage of MMT.

`!SideDescriptionIfa` - This is the actual data for each channel.

Level Detector

The level detector is obtained by creating the envelope using one of the two methods and then changing it into a specified number of levels. This data is output for a number of points as specified by you.

The data that is output to the GCD file is:

`!DetectorNumLevels` - This is the number of levels of the detector.

`!DetectorLevels` - These are the actual levels of the detector.

`!SideDescriptionLevels` - This is the actual data for each channel.

Spectrum of the signal

The amplitude spectrum of the selected EMG channels can be written to the GCD file. You have the option to select the start and end of the window (in terms of % gait cycle) and also the frequency till which the data is plotted.

The data that is output to the GCD file is:

`!SpectrumPlotFromFreq` - This is the frequency from which the amplitude spectrum of the selected channel is plotted.

`!SpectrumPlotTillFreq` - This is the frequency till which the amplitude spectrum of the selected channel is plotted.

`!SideDescriptionSpectumStartWindow` - This is the start of the window in terms of percentage gait cycle. This is written for each channel.

`!SideDescriptionSpectumEndWindow` - This is the end of the window in terms of percentage gait cycle. This is written for each channel.

`!SideDescriptionSpectrum` - This is the actual data that is plotted.

Power Spectrum of the signal

The power spectrum of the selected EMG channels can be written to the GCD file. You have the option to select the start and end of the window (in terms of % gait cycle) and also the frequency till which the data is plotted.

The data that is output to the GCD file is:

`!PowerSpectrumPlotFromFreq` - This is the frequency from which the amplitude spectrum of the selected channel is plotted.

`!PowerSpectrumPlotTillFreq` - This is the frequency till which the amplitude spectrum of the selected channel is plotted.

`!SideDescriptionPowerSpectumStartWindow` - This is the start of the window in terms of percentage gait cycle. This is written for each channel.

`!SideDescriptionPowerSpectumEndWindow` - This is the end of the window in terms of percentage gait cycle. This is written for each channel.

`!SideDescriptionPowerSpectrum` - This is the actual data that is plotted.

Correlation of two muscles

It is possible to carry out the correlation of two muscles in the data file.

The data that is output to the GCD file is:

`!CorrelationPlotTillGC` - This is the percent of Gait Cycle till which the correlation is carried out.

`!SideDescription1Description2Correlation` - This is the actual data that is plotted.

Window menu

This menu contains commands that are useful in arranging the open windows in the application workspace.

Cascade

This command can be used to arrange multiple opened windows in an overlapped fashion.

Tile

This command can be use to arrange multiple opened windows in an non-overlapped fashion.

Arrange Icons

This command can be used to arrange the icons for minimized windows at the bottom of the main window. If there is an open document window at the bottom of

the main window, then some or all of the icons may not be visible because they will be underneath this document window.

1,2, … filename

The application displays a list of currently open document windows at the bottom of the Window menu. A check mark appears in front of the file name of the active window. Choose a file from this list to make its window active.

Help

Using the Help system

The ***EMG Analysis*** and ***EMG Graphing*** programs are supplied with a standard help file that contains all the information that the electromyographer is likely to need while running the program. This file can be indexed and searched and can be used in conjunction with the printed user manual as both documents have a similar structure and content. Note that the user manual may contain more detailed information on the mathematics and analysis details and should be considered the reference source for this kind of information.

The Help system is accessed from the help menu that contains the following items:

Help Topics

The application supports several different types of context-sensitive help. Help is available by highlighting a menu item and then clicking the F1 key – this will take you directly to the relevant help information for the subject.

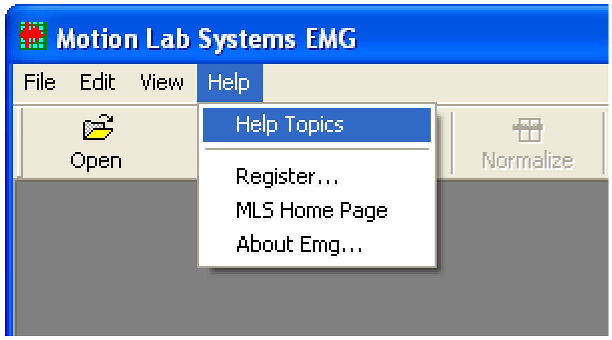


Figure 123 - The help menu options.

Help can also be sought by clicking the Shift-F1 keys. This transforms the cursor into a help cursor and allows the electromyographer to click on the item of interest to see the help topic associated with it.

Simply clicking on the Help Topics menu option opens the help file and displays the table of contents, showing the various help topics that are available. These topics can be indexed and searched for any item of interest or simply browsed if you are looking for general information.

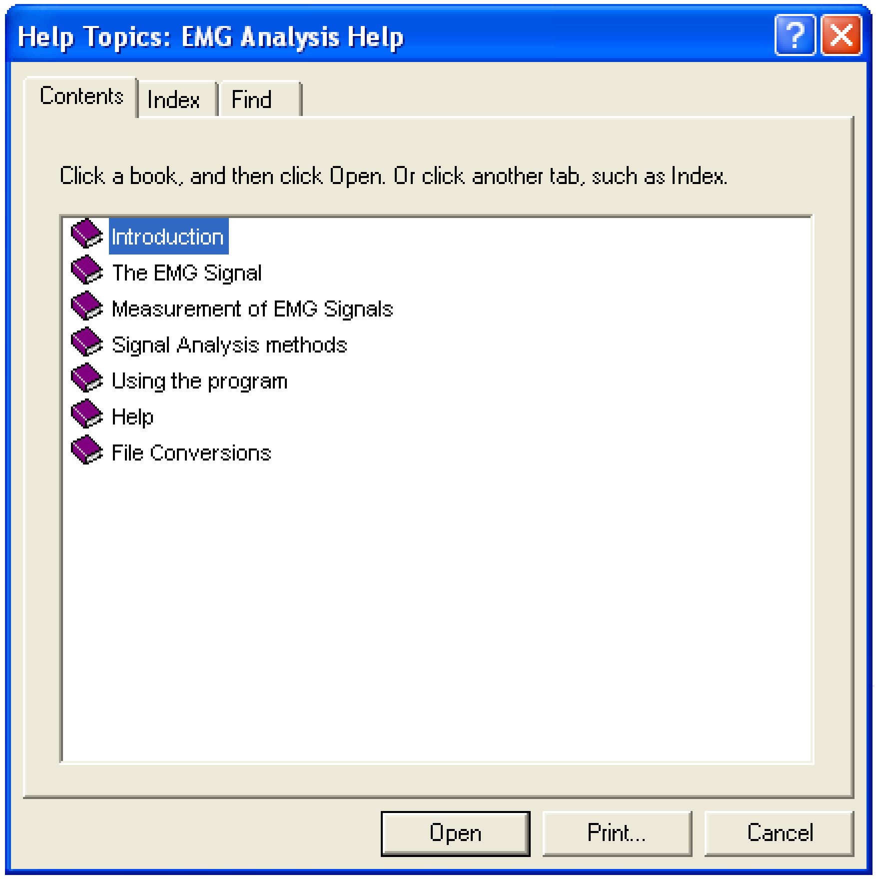


Figure 124 - The help system 'table of contents'

Register

This command enables you to register this application if you have previously downloaded an evaluation copy and subsequently purchased a registration key for the program. Motion Lab Systems registration keys consist of a User Name, Organization Name and a sixteen-digit serial number together with checksum information.

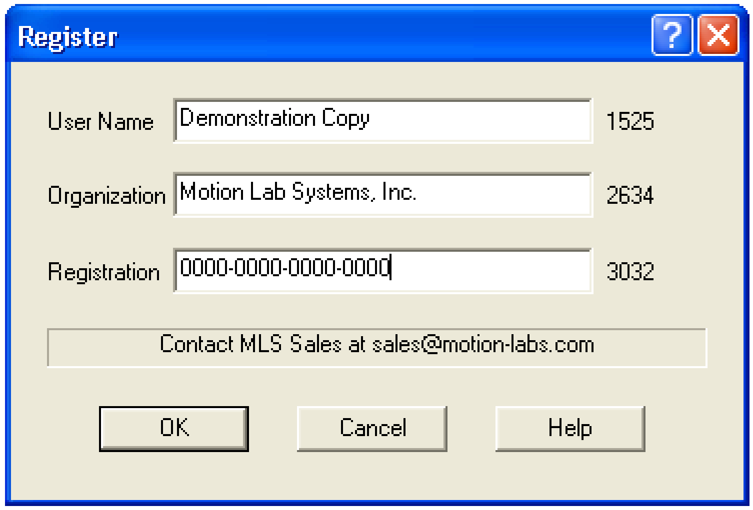


Figure 125 - The Registration dialog box

MLS Home Page

If you have an Internet connection then you can launch your Internet Web browser directly from this item and visit the Motion Lab Systems Home Page. You can check here for new updates to this application as well as download evaluation copies of other Motion Lab Systems software products. You can also contact Motion Lab Systems technical support directly from the Motion Lab Systems web site.

About EMG

This opens a dialog box provides information about the application, including the User Name and Organization that is the registered to use the software application. Note that, unlike most competing software products, Motion Lab Systems software is licensed to sites and not to individual computers thus it is quite normal to find the same software installed on several different systems within a single lab.

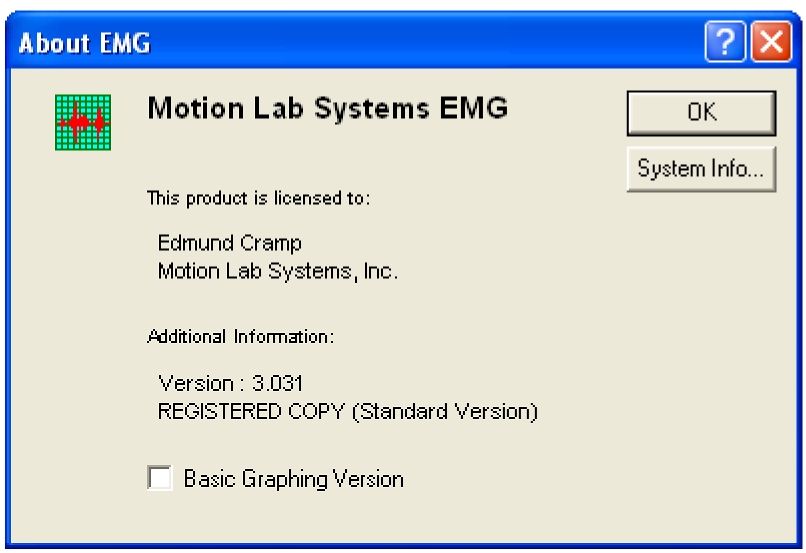


Figure 126: About EMG dialog box

This dialog box also displays the version number of the software – you can check this number against the current version available from the Motion Lab Systems web site to make sure that you are running the most current version.

System Information

The System Info… button runs a Microsoft application that displays information about the operating environment and is sometimes useful for debugging problems.

Basic Graphing Version

This box is only shown in the full ***EMG Analysis*** version of the software **-** checking this box will restrict the application functionality to those functions available in the ***EMG Graphing*** version of the software.

File Conversions

Discussion

The ***EMG Analysis*** and ***EMG Graphing*** programs read several different motion capture and data collection manufacturers file formats in addition to the default, industry standard C3D file format. All non-C3D data files that are read by this application are converted to the C3D file type when the information is saved – the information in the original manufacturers file remains unchanged.

Any relevant parameters in header sections of these files are converted to parameters and stored in the Parameter section of the C3D file.

The application creates some additional parameters required of compatibility with the C3D file and also to help you to store things like the Labels that are to be associated with each channel.

To make it easier for you, all these additional parameters are written to a Parameter file (*.PRM), which is then looked at when you open the next file and the defaults are applied to the files.

A dialog box opens for each file conversion and they contain the following controls:

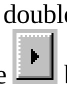
Parameter File

This is the name of the parameter file in use.

Create New Parameter File

When you leave this box checked, the application will save the parameters that are created to a new file. The application will allow you to choose the name and location of the file before it is saved.

Channels

This is a list control that shows you some of the parameters associated with each channel. You can select one or more items in the list at any time. If only one item is selected, you can edit the parameters by double clicking on the parameter. If multiple items have been selected you can use the  button to select one of the following commands:

- Type: Other
  Sets the type of information in all the selected channels collected to OTHER.
- Type: EMG Channel
  Sets the type of information in all the selected channels collected to EMG data.

- Type: Force Plate
  Sets the type of information in all the selected channels collected to Force Plate data.
- Type: Foot Switch
  Sets the type of information in all the selected channels collected to foot switch data.
- Side: Left
  Sets the relevant side for the selected channel to the left side.
- Side: Right
  Sets the relevant side for the selected channel to the right side.
- Side: None
  Specifies that the selected channels are not relevant to any side.

The sections below describe how the different file types are converted to C3D files.

Oxford Metrics ADC Files

Files with the type .ADC were created by Oxford Metrics Ltd., VICON systems running on the DEC PDP-11/RSX11-M system and DEC VAX/VMS systems. Several different variations of the basic .ADC file format exist depending on the operating system and environment used to collect the original data.

The following C3D parameters are created when an Oxford Metrics .ADC file is converted to a C3D file:

ANALOG: LABELS

These are the labels that are assigned to each analog channel. Defaults to *CHnnn* where *nnn* is the channel number.

ANALOG: DESCRIPTIONS

These are the descriptions for each analog channel in the data file. These default to *Channel nn* but are usually changed to muscle names once EMG channels are defined.

EMG: TYPE

This is the type of data present in each channel. The types used are EMG Channel, Foot Switch Channel, Force Plate Channel and Other.

EMG: SIDE

This is the side (left or Right) to which the channel belongs. This is needed only for channels with EMG data.

ANALOG: OFFSET

This is the offset applied to each channel and default 2048 – all VICON .ADC data is 12-bit resolution.

ANALOG: SCALE

This is the scale factor applied to each channel (default 1.0).

ANALOG: GEN_SCALE

This parameter holds information about a scale factor that is applied to all channels. Defaults to 10/2048.

POINT: RATE

This is the rate at which the video data is collected in Hertz. The analog rate is the same as the video rate.

The following parameters are created based on the data read from the file:

ANALOG: USED

This is the number of analog channels that are present in the data file.

ANALOG: RATE

This is the rate at which the analog data is collected.

POINT: FRAMES

This is the number of frames of video data. This is computed from the video rate entered by you and the analog rate and the analog frames of data.

The following parameters are created, but you will not get a chance to edit them at this point. They are used to store the information of certain processes in the application:

EMG: GAIN

This parameter is used to store the calibration data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

EMG: NORMALIZATION

This parameter is used to store the normalization data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

BTS EMG Files

The following parameters are created when an BTS file is converted to a C3D file. These parameters can be edited before the data file is opened:

ANALOG: LABELS

These are the labels that are assigned to each channel. Defaults to CHnnn.

ANALOG: DESCRIPTIONS

These are the descriptions for each channel in the data file. Defaults to Channel nn.

EMG: TYPE

This is the type of data present in each channel. The types used are EMG Channel, Foot Switch Channel, Force Plate Channel and Other.

EMG: SIDE

This is the side to which this channel belongs. This is needed only for channels with EMG data.

The following parameters are created based on the data read from the file:

ANALOG: SETUPFILE

This is the name of the set up file and this information is present in the data file.

ANALOG: USED

This is the number of analog channels that are present in the data file.

ANALOG: GAIN

This is a Gain factor that is obtained from the data file.

ANALOG: HPFREQ

This is the high pass cut off frequency.

ANALOG: LPFREQ

This is the low pass cut off frequency.

ANALOG: RECTIFICATION

This shows you if the data is rectified or not. If data is rectified the value is 1, if not it is zero.

ANALOG: INTEGRAL

This is the integral value of the signal.

ANALOG: EXECUTION

This is the execution method used.

ANALOG: FSWPRESENT

This shows you if foot switch data is present (1) or not(0).

ANALOG: RATE

This is the rate at which the analog data is collected.

ANALOG: SCALE

This is the scale factor applied to each channel and is acquired from the data file.

The following parameters are created, but you will not get a chance to edit them at this point. They are used to store the information of certain processes in the application:

EMG: GAIN

This parameter is used to store the calibration data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

EMG: NORMALIZATION

This parameter is used to store the normalization data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

ANALOG: GEN_SCALE

This parameter holds information about a scale factor that is applied to all channels. Defaults to 1.

ANALOG: OFFSET

This is the offset applied to each channel (default 0).

POINT: RATE

This is the rate at which the video data is collected in Hertz. The video rate is assumed to be a tenth of the analog rate.

Dataq CODAS Files

The following parameters are created when a Dataq CODAS file is converted to a C3D file. These parameters can be edited before the data file is opened:

ANALOG: LABELS

These are the labels that are assigned to each channel. Defaults to CHnnn.

ANALOG: DESCRIPTIONS

These are the descriptions for each channel in the data file. Defaults to Channel nn.

EMG: TYPE

This is the type of data present in each channel. The types used are EMG Channel, Foot Switch Channel, Force Plate Channel and Other.

EMG: SIDE

This is the side to which this channel belongs. This is needed only for channels with EMG data.

The following parameters are created based on the data read from the file:

ANALOG: USED

This is the number of analog channels that are present in the data file.

ANALOG: RATE

This is the rate at which the analog data is collected.

The following parameters are created, but you will not get a chance to edit them at this point. They are used to store the information of certain processes in the application:

EMG: GAIN

This parameter is used to store the calibration data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

EMG: NORMALIZATION

This parameter is used to store the normalization data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

ANALOG: GEN_SCALE

This parameter holds information about a scale factor that is applied to all channels. Defaults to 1.

ANALOG: SCALE

This is the scale factor applied to each channel and is set to 1.0.

ANALOG: OFFSET

This is the offset applied to each channel (default 0).

POINT: RATE

This is the rate at which the video data is collected in Hertz. The video rate is assumed to be a tenth of the analog rate.

Motion Analysis Corporation ANA Files

The following parameters are created when a Motion Analysis Corporation ANA file is converted to a C3D file. These parameters can be edited before the data file is opened:

ANALOG: LABELS

These are the labels that are assigned to each channel. Defaults to CHnnn.

ANALOG: DESCRIPTIONS

These are the descriptions for each channel in the data file. Defaults to Channel nn.

EMG: TYPE

This is the type of data present in each channel. The types used are EMG Channel, Foot Switch Channel, Force Plate Channel and Other.

EMG: SIDE

This is the side to which this channel belongs. This is needed only for channels with EMG data.

ANALOG: GEN_SCALE

This is the general analog scale factor that is applied to all channels. The default value is 10/2408.

ANALOG: SCALE

This is the scale factor applied to each channel and is obtained from data in the file.

ANALOG: OFFSET

This is the offset that is applied to each channel (default 2048).

The following parameters are created based on the data read from the file:

ANALOG: USED

This is the number of analog channels that are present in the data file.

ANALOG: RATE

This is the rate at which the analog data is collected.

The following parameters are created, but you will not get a chance to edit them at this point. They are used to store the information of certain processes in the application:

EMG: GAIN

This parameter is used to store the calibration data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

EMG: NORMALIZATION

This parameter is used to store the normalization data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

POINT: RATE

This is the rate at which the video data is collected in Hertz. The video rate is assumed to be a tenth of the analog rate.

VAD Files

In the case of VAD files, the application looks for the associated session file with the .CAR extension in the same directory as the data file and tries to read the parameter based information from that file.

The following parameters are created when a VAD file is converted to a C3D file. These parameters can be edited before the data file is opened:

ANALOG: LABELS

These are the labels that are assigned to each channel. This information is present in the session file.

ANALOG: DESCRIPTIONS

These are the descriptions for each channel in the data file. This information is present in the session file..

EMG: TYPE

This is the type of data present in each channel. The types used are EMG Channel, Foot Switch Channel, Force Plate Channel and Other.

EMG: SIDE

This is the side to which this channel belongs. This is needed only for channels with EMG data.

ANALOG: GEN_SCALE

This is the general analog scale factor that is applied to all channels. This information is present in the session file.

ANALOG: SCALE

This is the scale factor applied to each channel. This information is present in the session file.

ANALOG: OFFSET

This is the offset that is applied to each channel. This information is present in the session file.

The following parameters are created based on the data read from the file:

ANALOG: USED

This is the number of analog channels that are present in the data file.

ANALOG: RATE

This is the rate at which the analog data is collected.

POINT: RATE

This is the rate at which the video data is collected.

POINT: FRAMES

These are the frames of video data in the file.

FORCE_PLATFORM: USED

These are the number of force platforms that are used in the data capture.

FORCE_PLATFORM: ZERO

These are the number of frames to have zero offset.

FORCE_PLATFORM: TYPE

This is the type of each force platform used.

FORCE_PLATFORM: ORIGIN

This is the origin of each force platform.

FORCE_PLATFORM: CORNERS

This parameter holds the corners of each force platform.

FORCE_PLATFORM: CHANNELS

This parameter holds the channels assigned to force platform.

The following parameters are created, but you will not get a chance to edit them at this point. They are used to store the information of certain processes in the application:

EMG: GAIN

This parameter is used to store the calibration data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

EMG: NORMALIZATION

This parameter is used to store the normalization data for each channel. The value assigned is -1, which implies that the channel is not calibrated.

Installing the Software

Overview

All of the Motion Lab Systems applications are written for the Microsoft Windows series of operating systems and should run on Windows98, Windows XP, Windows NT, Windows 2000, Windows XP and Windows Vista. Although unsupported, all Motion Lab Systems applications have been tested and run on Linux and FreeBSD under *Wine. Wine* is a software application which allows many UNIX based operating systems on the x86 architecture to execute programs written for Microsoft Windows.

All Motion Lab Systems software applications use the same installation package and, as a result, they all install in the same manner with only minor differences between applications. The installation process will check to see if a previous version of the software is installed and then perform the appropriate updates if necessary. During the installation it will backup any files that have changed and then copy all of the required files to your computer. The system Registry will be updated to store information about the new version.

The installation of all Motion Lab Systems software will require modifications to the Registry to store the program registration information – this will require Administrative Privileges during the installation process only. Normal operation of Motion Lab Systems software by the user does not require Administrative Privileges.

All Motion Lab Systems software is available in two different versions, an installation version and an update version identified by the words *_install* and *_update* appended to the application name. The *_install* version contains all of the files required to install the application, while the smaller *_update* version contains only the most recent changes to the program. If in doubt, download and install the full *_install* version.

Installation

The installation program can be downloaded to your computer via a link from the Motion Lab Systems web page or directly from the FTP site. If your computer does not have internet access then you can download the executable file to another computer and copy it to your computer via a USD drive, LAN or CD-ROM. The installation file will be called *name_install.exe* where *name* is the name of the software being installed.

The first installation screen will ask the user to choose the language for the installation – you can choose any of the displayed options to select your preferred language if it is not English.

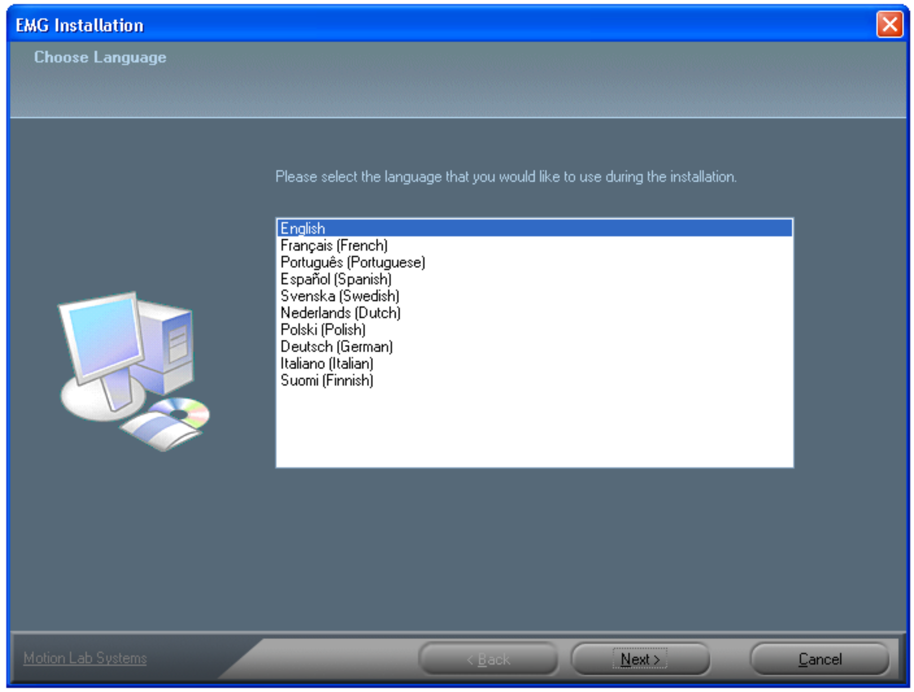


Figure 127 - Choose your language for the installation.

Once you have chosen your language, click on the *Next* button to start the installation – this will then continue in the selected language. The following illustrations all use English as this is the default selection.

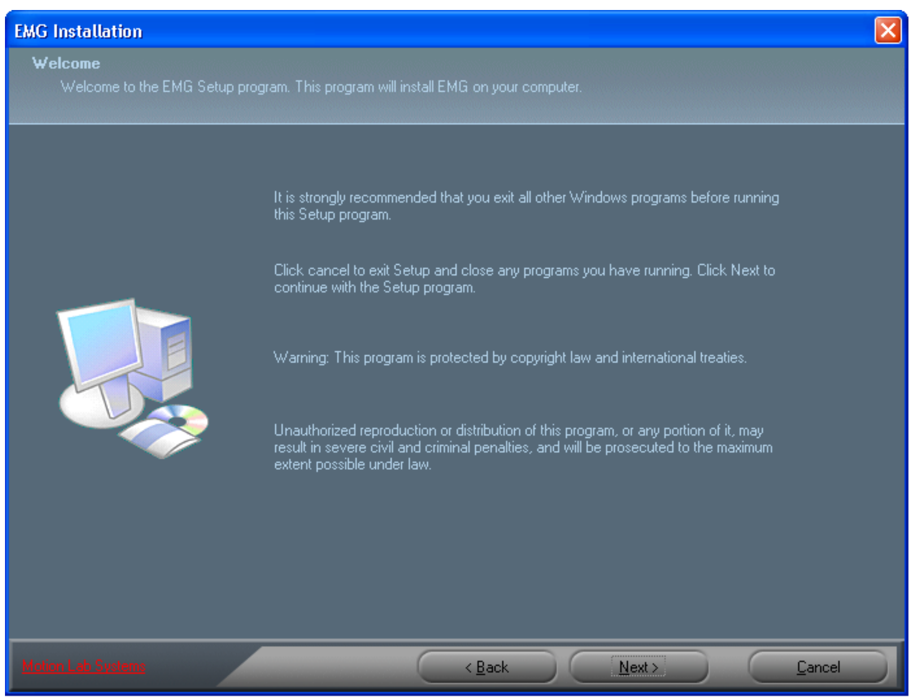


Figure 128 - The Welcome screen starts the installation process.

The first installation screen will display the usual notifications about licensing protections and international copyright treaties. Click on the *Next* button to proceed with the installation – the license conditions for the software will be displayed before the installation starts and you will have the chance to accept or reject the installation at that time.

You must own or use an EMG system sold by Motion Lab Systems to install the EMG Graphing software.

You will then be asked if you are installing the ***EMG Graphing*** version of the software – this is the basic version of the ***EMG Analysis*** software that is included with all Motion Lab Systems EMG system. If you have purchased a license for the full copy of the ***EMG Analysis*** software then you should answer *N*o at this point, otherwise, if you own one of our EMG systems then you may answer *Yes*.

If you do not own or use an EMG system manufactured by Motion Lab Systems then you must purchase a license from Motion Lay Systems to legally use the EMG Graphing software with a custom built EMG system, or an EMG system manufactured by another company.

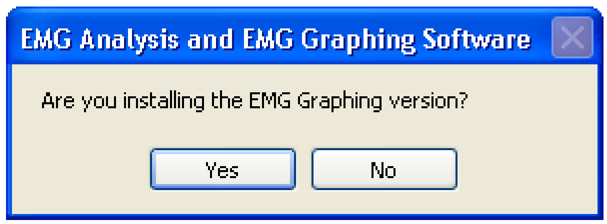


Figure 129 - EMG Graphing is supplied with our EMG systems.

If you answered *Yes* (the default answer) to install the ***EMG Graphing*** software then the installation will skip ahead to the Readme screen in the installation process. The next question shown below, and the later registration panel, will not be displayed. This question and the registration screen will only be displayed if you are not installing the ***EMG Graphing*** version.

If you are not installing the ***EMG Graphing*** version then the next question will ask if you want to install the evaluation version – the evaluation version is a fully functional copy of ***EMG Analysis*** software that works with the sample C3D files that are installed with the application. The evaluation version installation is the default option at this point and can legally be installed by anyone interested in evaluating or learning to use our software. Answer *Yes* to install the evaluation version.

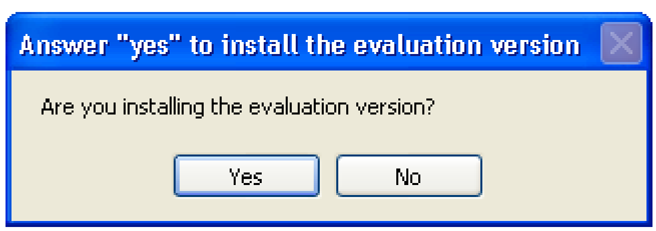


Figure 130 - The evaluation version is a demo version of the full EMG Analysis program.

This is the last question required to configure the installation process – you must answer *No* to install a copy of the fully functional licensed ***EMG Analysis*** software that can be used to open and process any C3D file containing EMG data. Answering *Yes* at this point will install the evaluation version however if you have a license, or subsequently purchase a license, then you can use the Register command within the application to complete the registration process and turn the evaluation version into a fully licensed version. Once the installer knows which version of the software to install it will display the License agreement for you to review and approve. You must check the box at the bottom of the license, indicating your acceptance of the license

terms which are legally binding. You must accept the terms before you can click on the *Next* button to proceed.

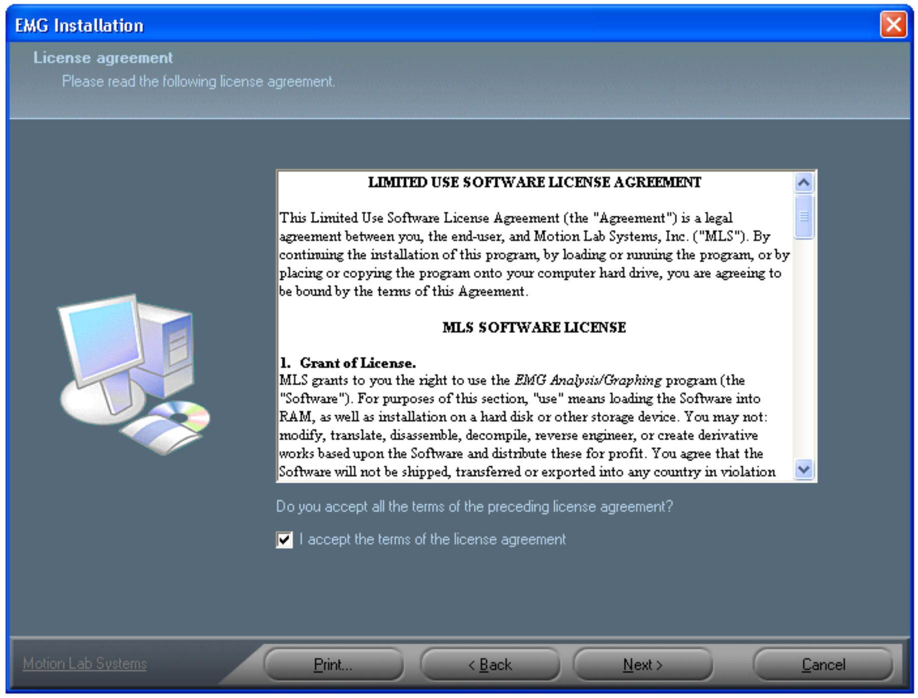


Figure 131 – The software license must be accepted to start the installation.

Unlike many applications, the ***EMG Analysis*** and the ***EMG Graphing*** programs are site licensed applications – this means that you can install multiple copies of these programs on any number of computers provided that the license conditions are met. Contact Motion Lab Systems if you have any questions about this policy.

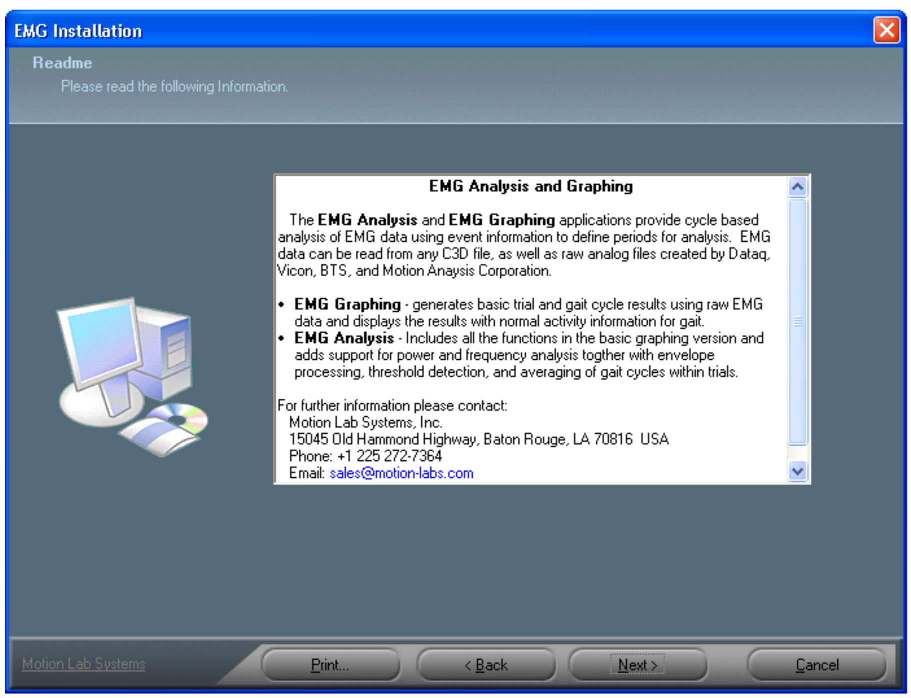


Figure 132 - The readme page provides some basic information about the application.

The Product Registration information is only required if you are installing the ***EMG Analysis*** program – this page is not shown if you are installing the evaluation version or the ***EMG Graphing*** version. The registration information will be created automatically if you are installing the ***EMG Graphing*** version but will be omitted if you are installing the evaluation version.

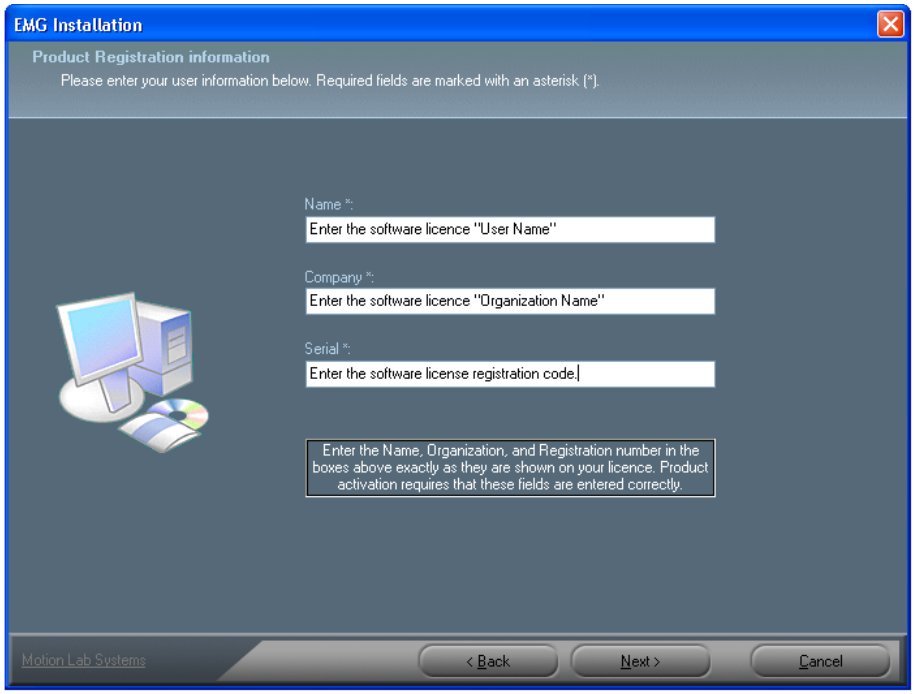


Figure 133 - Registration is required when installing a licensed copy of EMG Analysis.

Please contact Motion Lab Systems if you have any questions about our software licensing policies.

The registration information is provided as either a printed paper license if you purchase the physical distribution of the ***EMG Analysis*** application or, if you purchase the product via electronic distribution then you will receive the license as either an Adobe PDF, or via email. All Motion Lab Systems software licenses are *site licenses*, permitting the program to be installed on multiple computers that meet the requirements.

The registration requirements for *site licensing* are simple and are defined by two entries in the registration page. These are the *Name* and *Company* entries which describe the environment in which the software is licensed. For example, if a copy of the software is purchased by the Biomechanics Lab at Zeppo Marx University, then the software can be legally installed and all of the follow situations:

- Any number of computers in the Biomechanics Lab at Zeppo Marx University.
- Any number of computers used by people working in the Biomechanics Lab at Zeppo Marx University.
- Personal computers and laptops used by people working in or with the Biomechanics Lab at Zeppo Marx University.

The software is not licensed for use on computers at Zeppo Marx University that are not owned or used in Biomechanics Lab, or computers owned or used by people who used to work in the Biomechanics Lab at Zeppo Marx University but no longer work there. You need a separate license in these situations.

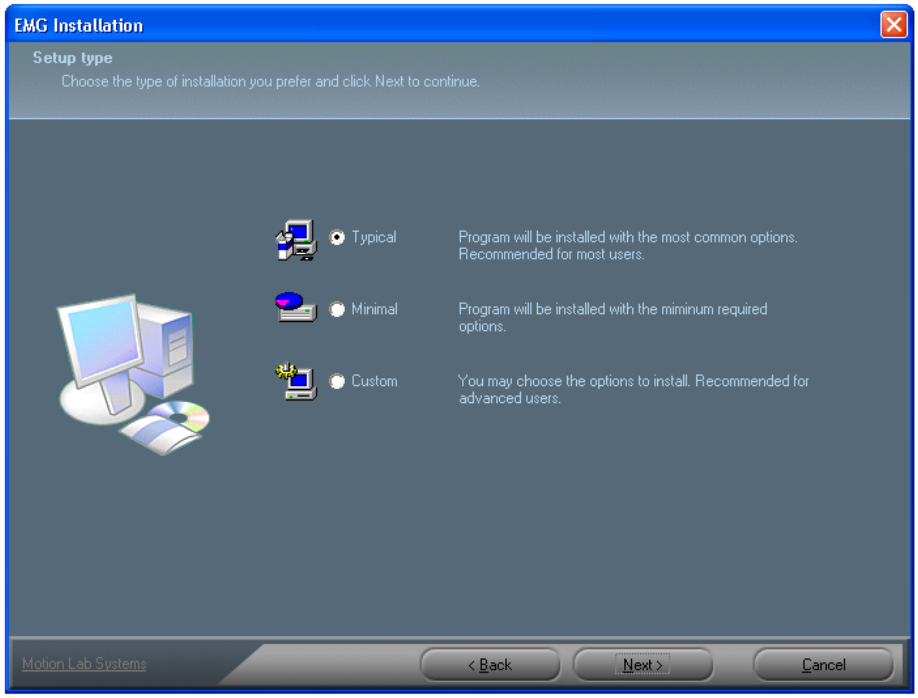


Figure 134 - You can select the type of installation suitable for your requirements.

The installation offers a number of different installation types – you can choose the *Typical* installation (which is the default), a *Minimal* installation, or a *Custom* installation. We recommend that the first installation of the software is always the default *Typical* installation unless there are special circumstances.

Select the Custom option if you want to select the components or optional features to be installed with the basic application and then click on the *Next* button to continue.

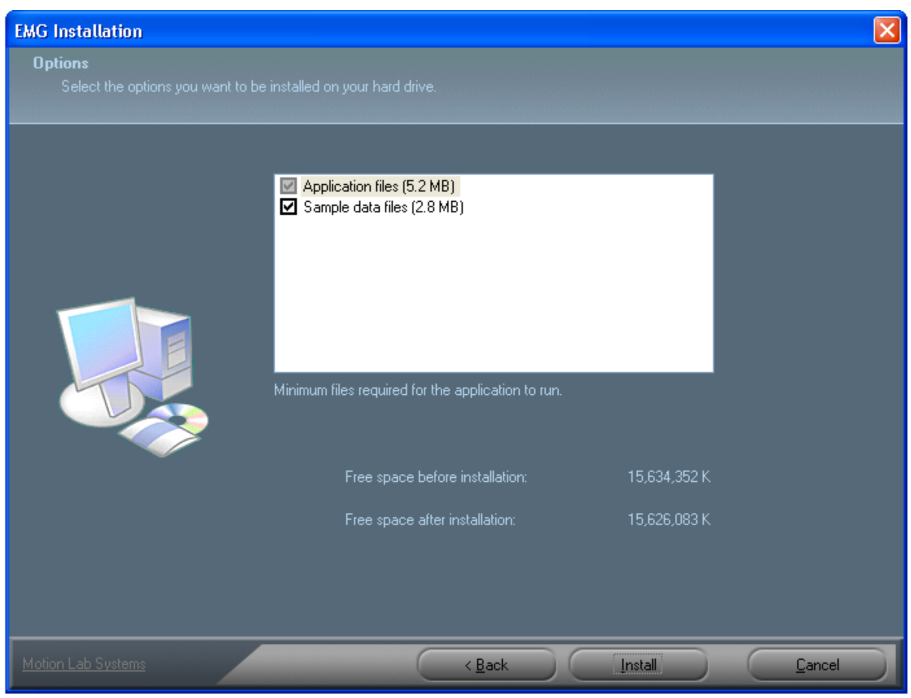


Figure 135 – The Custom option allows you to choose which options are installed.

Clicking on the *Next* button after the installation type is selected will start the actual installation process. This will copy the required files to your computer, enter the registration information and make a backup of any important files from previous installations.

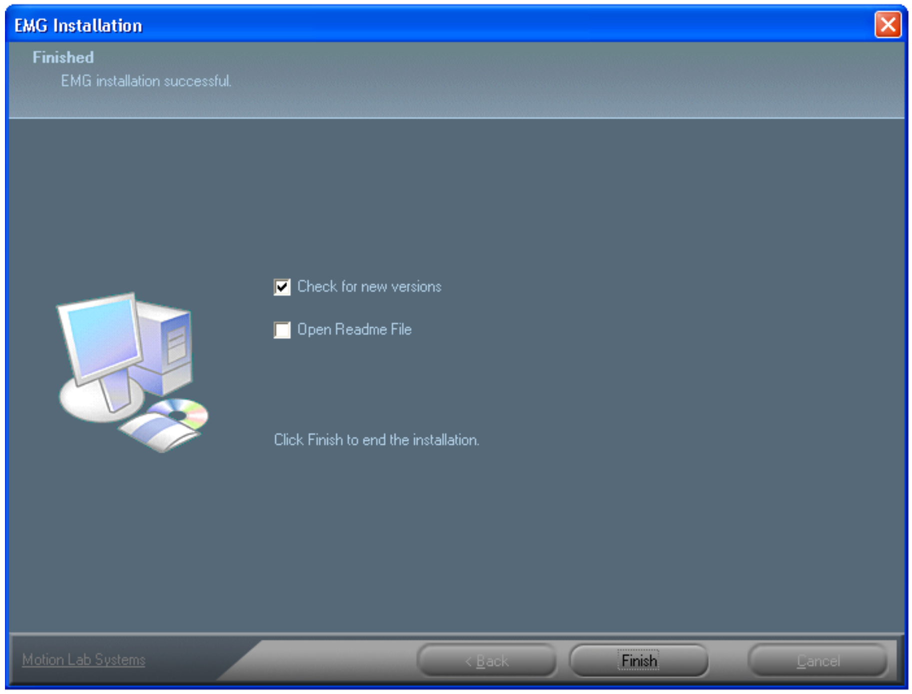


Figure 136 - You can automatically check for bug fixes and new versions of the software.

Once the installation is completed you will be offered the chance to view the readme file (detailing any changes or known issues with the current release) and, if you are connected to the internet, you have the option of checking that you have the current version installed. Click *Finish* to complete the installation and exit from the installation program. When you click Finish the readme file will be displayed if that option was selected and, if desired, the AutoUpdator will run.

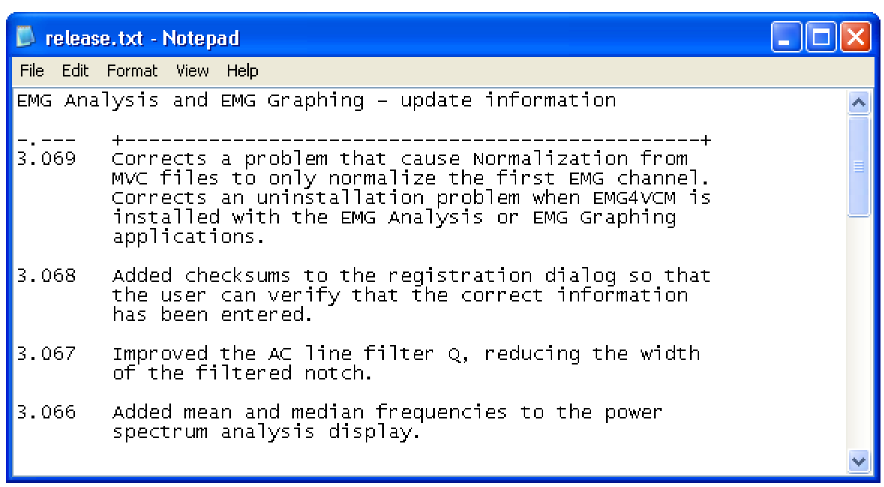


Figure 137 - The readme file contains information about bug fixes and changes to the program.

Updating to the Current Version

The latest version of the ***EMG Analysis*** or ***EMG Graphing*** program is always available from our website at http://www-motion-labs.com – in addition an autoupdater tool from Thraex Software is supplied with the programs. This tool will check to see if there is a more recent version of the installed program available and, if an update exists, then it can be (optionally) downloaded and automatically applied to your computer to make sure that you are running the latest version.

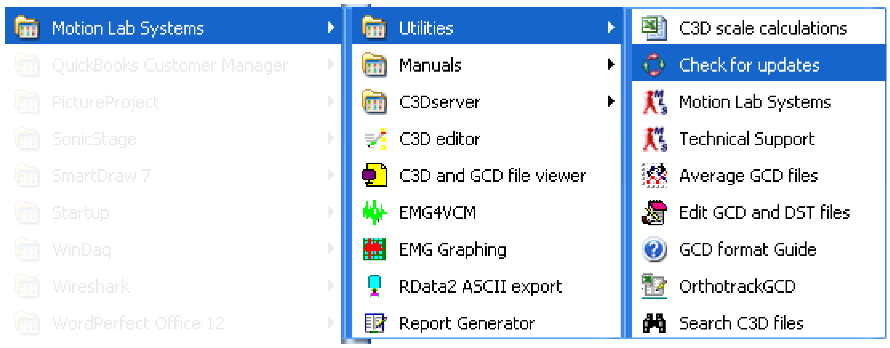


Figure 138 - The autoupdater tool is available from the Program Menu

This update checking utility can be run at the end of a program installation or manually by selecting *Check for Updates* from the *Utilities menu* within the *Motion Lab Systems program group* on most computers.

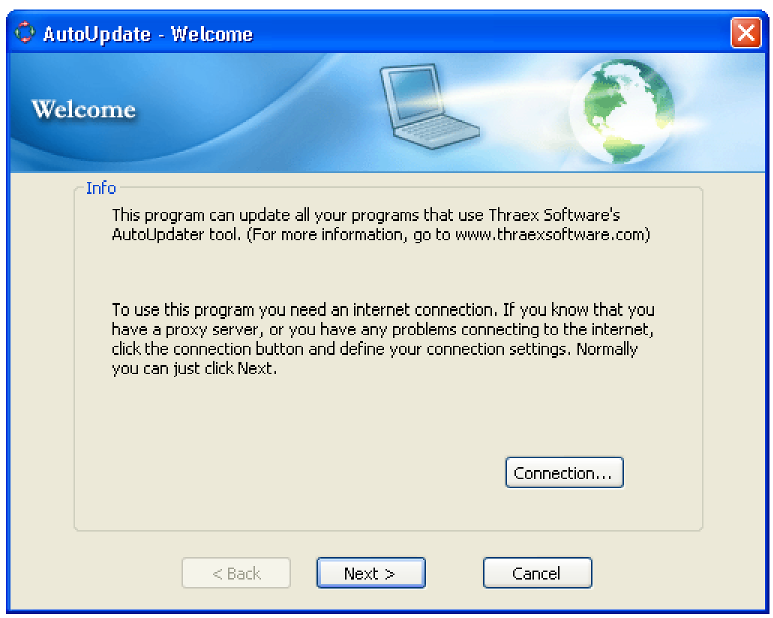


Figure 139 - The autoupdater welcome screen – click Next to check for updates.

The autoupdater tool requires that the computer is connected to the internet so that it can contact our FTP site to download an XML file that stores the current version information. This process does not transmit any information about your system to us other than requesting a filename.

If you have problems connecting to download the current version information then you may need to provide the autoupdater with your proxy information or contact your network administrator.

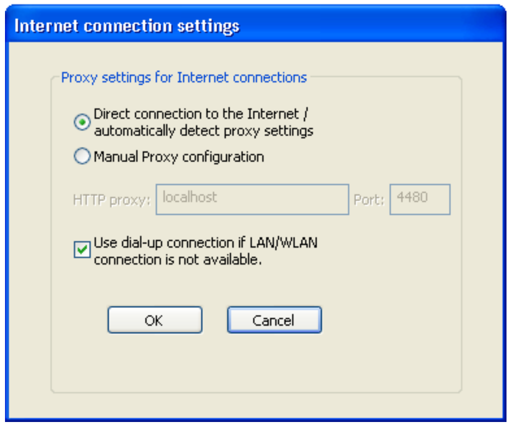


Figure 140 - Proxy information may be needed.

If you access the internet via a firewall then you may need to permit the autoupdater application to access the internet or ask your LAN administrator to help you configure your computer. Once the autoupdater has downloaded the XML files containing the current version information from our servers it will compare the available versions to the versions installed on your hard drive and display a list of available updates. You can then proceed by clicking on the *Next* button if you chose.

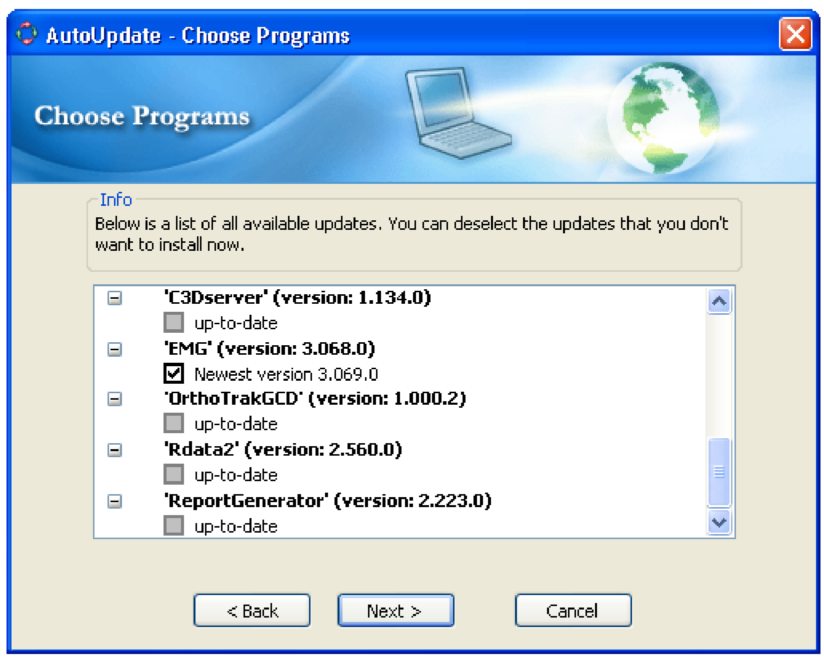


Figure 141- A list of available updates is displayed by the autoupdater.

When you click the *Next* button the autoupdater tool will automatically download all the available updates, one after another, and then install them – if the autoupdater requires an update itself then that will always be downloaded and installed first from the Thraex web site. A progress bar will be displayed showing you the total amount of data downloaded and the percentage of each application when multiple downloads are selected.

Removing the Software

The software can be completely removed from the computer at any time via the Add/Remove Programs option within the Windows control panel. Removing the software will delete all of the files that were originally installed or updated via the AutoUpdator utility since the original installation. It will not remove files that have been changed or modified, and it will not remove files that have been manually added to the various program directories.

Removal of the software is a complete process and includes deletion of the registration information used to install the program initially. If you need to reinstall the software then you will need to re-enter the original registration information.

Manual removal of the software can be performed by running the appropriate program in the default application root directory – this is called *remove_emg.exe* in the *C:\Program Files\Motion Lab Systems* directory.

EMG Reporting Standards

Introduction

Although it is not usually required, it is very helpful to specify the manufacturer of the EMG equipment used in a study and the modules or items used.

When presenting EMG data, or writing a paper about EMG, it is important that you provide all the information necessary for another researcher to understand and possibly attempt to reproduce or validate your research results. The study of electromyography is a broad field and it should not be assumed that every reader or researcher would be intimately familiar with the details that are common within your area of study or specialty. The following lists are not comprehensive to every research project or paper – this is intended as simply a series of suggestions to start you thinking about the factors that might influence your study and that might need to be documented if the data and results are to be reproduced.

The following discussion traces the EMG signal from the muscle through detection, amplification, physical signal processing, data storage, and analysis. It's not essential that you address every one of these points when studying EMG data but you would be well advised to be able to address them if you submit research for review or publication.

While electromyography research can be intellectually satisfying, in the end it is critical that the research must be of use to other researcher, academics and clinicians if there is to be any justification for the effort expended. The research must be based on quality data, thorough analysis, and properly reasoned interpretation – yet all this is not enough if the results can not be reproduced by another researcher. The following notes are largely based the "Standards for Reporting EMG Data" by Dr. Roberto Merletti and published in the Journal of Electromyography and Kinesiology.

EMG Electrodes

The electrode is the means by which the electromyographic signal is detected and collected. There are generally considered to be two types of electrode, non-invasive electrodes which collected EMG from the outer skin surface and do no penetrate the body, and invasive electrodes that collect EMG from within the muscle and penetrate the skin surface.

The frequency content of surface EMG signals is affected by the type and spacing of the electrodes used to record the signal so it is important to state the inter-electrode distance, and precisely describe the location of the EMG electrodes together with their orientation over muscle with respect to tendons, motor point and fiber direction.

Reports on surface EMG recordings should describe the electrode material (e.g., silver/silver-chloride, gold, stainless steel, etc.), the electrode size and shape (discs,

bars, diameter, length and width, etc.) and the inter-electrode distance (center to center).

If a commercial gel electrode is used then state the Manufacturer and type.

The use of any electrode gel or paste, and skin cleansing should be reported, paying particular attention to the degree of skin abrasion (if any). Note too if the subject requires shaving to remove excessive hair, although this is rarely essential with human subjects.

It is also very important to clearly document the electrode location and the orientation of the electrode over the muscle with respect to tendons, motor point and fiber direction. However, it is worth noting that these requirements are much easier to recommend than actually implement yet all of these factors can affect the amplitude of the recorded signal.

If a commercial fine-wire electrode is used then state the Manufacturer and part number.

Fine wire (or intramuscular) electrodes should include similar information that would allow another researcher to duplicate the exact recording conditions so it is important to document the electrode materials (e.g., platinum, stainless steel) and the electrode construction (single wire, multi-strand, insulation material, length of exposed tip) as well as the method of insertion.

The precise location of the fire-wire electrode within the muscle is very important in intramuscular recording so it is important to record the depth of insertion and the position of electrode within the muscle. It's worth noting that while all of these properties affect the quality of the recorded EMG signal, they can be very difficult to accurately document and reproduce.

It's also worth documenting the use of any ground reference electrode used and its location – this is essential if you are using any type of monopolar electrode, but is usually unimportant if you have a modern EMG system using differential EMG signal collection methods. The actual location of the ground reference electrodes generally has very little effect on the recorded EMG data but documenting it allows other researchers to reproduce your experimental conditions.

Monopolar needle electrodes are uncommon in most gait and motion studies – they are typically used in nerve conduction and specialized research studies. If used, the application of the needles should be described and should include information about the material, gauge, and number and size of conductive contact points at the tip, in addition to the other details documented above.

EMG Amplification

If using a commercial EMG system then state the Manufacturer and model number of the system used.

The equipment used to detect and amplify the EMG signal needs to be described. In many cases, if you are using a commercial EMG system with published specifications then it may be sufficient to simply document the manufacturer and model number. However if other researchers are to be able to repeat the research, or if you are using any custom built equipment then it is essential to document the main features of the amplification system.

Once the EMG signal has been detected it is amplified from the low levels available at the electrode (typically 10uV to 5mV) to a level that is convenient to record and study. Both the method used to acquire the raw EMG signal from the electrodes, and the characteristics of the amplification system should be described as they affect the content of the EMG signal that will be subsequently used for interpretation and/or analysis.

Document the front-end electronic configuration - normally differential, although monopolar, and double differential are not uncommon, as well as the front-end input impedance, and the Common Mode Rejection Ratio (CMRR).

If you are using a pre-amplified EMG system with separate EMG amplifiers mounted on the skin surface, or close to the insertion site, then you may need to characterize the preamplifiers separately from the main EMG system. It is important to be able to state the total system gain applied between the EMG detection at the subject and the measurement and/or recording of the EMG signal.

In addition to the front-end configuration, you will need to document the overall system signal-to-noise ratio (SNR) and the total system gain used as well as the actual frequency response of the system. In most cases this information can be extracted from the manufacturers documentation if you are using a commercial EMG system but it's worth noting measurements of both the signal-to-noise ratio and frequency response are not trivial measurements and the figures available from equipment manufacturers may be misleading – for example, there is a considerable difference in performance between system with a frequency response of 10Hz to 500Hz -3dB and a system with a response of 10Hz to 500Hz -6dB.

Analog Signal Processing

Always state the frequency response of the EMG system used and verify the frequency performance of the system matched the manufacturers specs.

An important characteristic of any amplification system is its frequency response, which is the band of frequencies over which the system produces similar output levels. All EMG amplifiers have a frequency response (which should be stated) and many systems have built-in electronic filtering circuits, which have specific characteristics. If an electronic filter is present in the EMG signal path then its type should be specified (e.g., Butterworth, Chebyshev, etc.) in addition to the high and low pass cut-off frequencies, and the filter quality (dB/octave).

In addition, the physical amplification and filtering of the electronic EMG signal will always introduce a time delay (often affected by the degree of filtering applied to the signal) that may be significant if the subsequent EMG Analysis is performed based on other events in the time-domain.

Note that any physical filtering of the EMG signal that is performed at this stage is distinctly separate from any filtering performed as part of the data-collection post-processing and must be documented as a specific process that is performed on the EMG data.

In general, it is recommended that the raw, unprocessed EMG signal be recorded. If this is not the case then any rectification or other processing of the signal prior to signal sampling must be specified.

Data Storage

Almost every modern EMG data processing system stores its data as a series of digital samples to allow the modern digital signal processing and analysis techniques to be applied to the EMG signal. Therefore it is important that the digitalization process is performed and specified correctly.

Most analog data storage formats record the sample rate as well as other parameters within the EMG data file.

The minimum data-sampling rate is twice the highest frequency that is removed by the low pass filter. This is not necessarily easy to calculate as it depends on both the filter frequency and the quality of the filter (in terms of dB/octave attenuation). For example if a low-pass filter of 500 Hz is used, the minimal sampling rate for the EMG signal would be 1000 Hz (500 x 2 as specified by Nyquist theorem) if the filter stopped all signal components above 500Hz. In practice, filters apply their attenuation gradually and a filter point of 500Hz may pass significant levels of signals up to 600-650Hz, which would generate signal aliasing artifacts if they were present. As a result to guarantee signal quality and accuracy and resolution, it is recommended that the sampling rates used for EMG data are always greater than twice the quoted low pass filter frequency.

Note that if rectification and smoothing with a low-pass filter (enveloping) is performed by the EMG system hardware prior to the data sampling operation then the EMG sampling rate can match the envelope frequency response rather than the raw EMG bandwidth. This can drastically reduce the amount of data stored, as well as reducing the overall data-sampling rate.

Always state the ADC resolution (number of data bits) used to collect the data, as well as the model, and manufacturer of the ADC card used to sample data.

Analysis

There are many common methods of EMG processing – most of these have common names that describe them but do not provide enough information to enable another researcher to duplicate the exact data processing and analysis. For instance, an EMG signal may be described as “enveloped”, or "linear envelope detection", neither of which is a precise description as they do not enable anyone else to reproduce the exact functions that were employed to generate the published results. A better description would be “an EMG signal with a bandwidth of 10-400Hz (-3dB) was full-wave rectified and then filtered with a low pass filter of (30 ms).

Remember that significant low pass filtering can introduce significant time-domain delays, and that many filter types (e.g. Chebyshev etc.,) can cause significant signal distortion - it is recommended that digital linear phase filters are employed were ever possible. All digital filtering of the EMG signal, and its associated delays (if any) must be documented.

Digital signal processing

Virtually all EMG analysis is performed digitally these days, offering many advantages over the older methods of analog processing but also adding some additional complexity and presenting new opportunities for processing errors. It is a our opinion that documenting the digital processing of EMG signals is a complex process that is often performed incompletely, making the reproduction of results and the duplication of research results difficult and often impossible.

For example, smoothing a rectified EMG signal with a low pass filter of a given time constant may be described as "smoothing with a low pass filter with a time constant of 15 ms" yet this does not describe the process with enough detail to allow another person to actually duplicate the processing. Missing from the description are details of the rectification (one would assume full-wave rectification but half-wave rectification is possible) and the smoothing method. Traditional analog processing, and simplistic, single-pass, digital processing always introduces some measurable delay into the EMG signal – however, modern digital filtering techniques permit dual-pass filtering with zero delays.

In general digital finite impulse response (FIR) linear phase filters are recommended for all EMG processing but it is important to verify both the frequency and pulse response performance of any filter used prior to actually processing EMG data.

Digital signal processing of the EMG signal usually involves complex mathematical processes including traditional techniques such as Fast Fourier Transforms (FFT) that require very specific descriptions. Typical descriptions of digital signal processing of the EMG signal spectrum include, the time epoch, the type of window used in the Fourier Transform (e.g. Hamming), zero padding of the data sample (if any) and the resultant frequency resolution. Calculations of complex properties such as the median and mean frequency of the EMG signal should include the equations used to derive the results. Basically, all processing techniques should be accompanied by full scientific and mathematical description.

Normalization

Whenever an attempt is made to correlate force and/or torque to an EMG signal it is usual to perform this relative to the values at maximal voluntary contraction (MVC). This common technique requires a certain level of expertise on the part of the researcher, and a degree of training of the subjects, in order to obtain good results. It is recommended that the reproducibility of the MVC training is reported as, without sufficient preparation, the results could be as much as 20-30% less than those obtained by another researcher. Since the normalization process results in the calculation of a single number (%MVC) from a complex signal (MVC EMG signal), the calculation method must be specified as well as descriptions of the physical conditions such as joint angles in isometric contractions and the range of angles, velocity, and load applied for non-isometric contractions.

EMG Crosstalk

Crosstalk from other muscles close to the muscle under study can contaminate the recorded signal even under the best of conditions. While the choice of electrode dimensions, size, separation and location can be carefully planned to avoid potential crosstalk problems, if is suggested that tests are performed and the results presented to allow an estimation of the possibility of crosstalk within the recorded data.

References

Sources used in this manual

Basmajian JV, et al. *Computers in Electromyography.* Butterworth, 1975.

Basmajian JV, Deluca CJ. *Muscles Alive: Their functions revealed by electromyography 5th ed.* Williams and Wilkins, Baltimore, 1986.

Basmajian JV, Stecko GA. *A new bipolar indwelling electrode for electromyography* J Applied Physiology, 17: 849, 1961.

Eberstein A, Beattie B. *Simultaneous measurement of muscle conduction, velocity, and EMG power spectrum changes during fatigue.* Muscle & Nerve, 8: 768-773, 1985.

Falconer K, Winter DA. *Quantitative assessment of co-contraction at the ankle joint in walking.* Electromyography and Clinical Neurophysiology, 25, 135-149 (1985).

Ganong WF. *Review of Medical Physiology 10th ed.* Lange, Los Altos, 1981.

Goldgood J. *Anatomical Correlates of Clinical Electromyography 2nd ed.* Williams and Wilkins, Baltimore, 1984.

Harris GF, Wertsch JJ. *Procedures for gait analysis.* Archives of Physical Medicine & Rehab, 75:216- 225, 1994.

Henneman E, Somjen G, Carpenter DO. *Excitability and inhabitability of motorneurons of different sizes.* J Neurophysiology, 28: 599-620, 1965.

Johnson EW. *Practical Electromyography 2nd ed.* Williams and Wilkins, Baltimore, 1988.

Kendall FP, McCreary EK. *Muscles, Testing and Function 3rd ed.* Williams and Wilkins, 1983.

Kimura J. *Electrodiagnosis in disease of Nerve and Muscle, Principles and Practice 2nd ed.* F Davis Co., Philadelphia, 1989.

Koh TJ, Grabiner MD. *Evaluation of methods to minimize crosstalk in surface EMG.* J Biomechanics, 26 Suppl: 151-157, 1993.

Kwatney E, et al. *An application of signal processing techniques to the study of myoelectric signals.* IEEE Transactions on Biomedical Engineering, Vol. BME-17, No. 4: 303-312, Oct 1970.

Merletti R, *Standards for Reporting EMG Data.* Journal of Electromyography and Kinesiology

Muro M, et al. *Surface EMG power spectral analysis of neuromuscular disorders during isometric and isotonic contractions.* American J Physical Medicine, 61(5): 244-253, 1982.

Nilsson J, Panizza M, Hallet M. *Principles of digital sampling of a physiologic signal.* EEG and Clinical Neurophysiology, 89: 349-58, 1993.

Norris FH. *The EMG: A Guide and Atlas for Practical EMG.* Gruve and Stratton, New York, 1963.

Perry J, *Gait Analysis: Normal and Pathologic Function.* Slack Incorporated, ISBN 1-55642-192-3, 1992

Seigler S, et al. *Effect of myoelectric signal processing on the relationship between muscle force and processed EMG.* American J Physical Medicine, 64(3): 130-149, 1985.

Shavi R. *Electromyographic patterns in adult locomotion: A comprehensive review.* J Rehab Res & Dev, 22(3): 85-98, July 1985.

Shavi R, Green N. *Ensemble averaging of locomotor electromyographic patterns using interpolation.* Med & Biol Eng & Computing, 21: 573-578, 1983.

Solomonow M, Baten C, Smit J, Baratta R, Hermens H, DíAmbrosia R. *EMG power spectra frequencies associated with motor unit recruitment strategies.* J Applied Physiology, 68: 1177-1185, 1990b.

Solomonow M, Baratta R, Bernardi M, Zhou B, Lu Y, Acierno S. *Surface and wire EMG crosstalk in neighboring muscles.* J Electromyography & Kinesiology, 4: 131-142, 1994.

Sutherland DH. *Gait Disorders in Childhood and Adolescence* Williams & Wilkins, Baltimore/London, ISBN 0-683-08026-1, 1984.

Sutherland DH, Olshen RA, Biden EN, Wyall, MP. *The Development of Mature Walking*, Mac Keith Press, ISBN 0-397-44622-5, 1988.

Sutherland DH. *The evolution of clinical gait analysis Part I: Kinesiological EMG.* Gait and Posture 14 (2001) 61-70.

Winter DA, Patla A. *Signal Processing and Linear Systems for the Movement Science.* Waterloo Biomechanics (ISBN 0-9699420-1-X).

Winter DA, Fuglevand AJ, Archer SE. *Crosstalk in surface EMG: theoretical and practical estimates.* J Electromyography & Kinesiology, 4(1): 15-26, 1994.

Winter DA. *The Biomechanics and Motor Control of Human Gait.* University of Waterloo Press, Waterloo, Ontario, 1988.

Winter DA, Rau G, Kadefors R, Broman H, Deluca CJ. *Units, Terms, and Standards in the Reporting of EMG Research: A Report by the AdHoc Committee of the International Society of Electrophysiology and Kinesiology.* Aug 1980.

Yang JF, Winter DA. *Electromyographic amplitude normalization methods: Improving their sensitivity as diagnostic tools in gait analysis.* Archives of Physical Medicine and Rehabilitation, 65 (9), 517-521 (1984).

Glossary of Terms

Abduction

Movement away from the midline of the sagittal plane.

Adduction

Movement towards the midline of the sagittal plane.

Adipose Tissue

The subcutaneous fat layer of skin between the surface of the skin and the muscle that attenuates the EMG signal before it reaches the surface of the skin. Thicker layers of adipose tissue produce a greater attenuation of the EMG signal than thinner layers.

Agonist Muscle

A muscle that initiates a contractive motion.

Antagonist Muscle

A muscle that provides a stabilizing force during a contraction or motion.

C3D

This is a file format developed in the early 1980s that stores synchronized 3D co-ordinate information and analog data together with information that describes the information contained within the file.

CAMARC

CAMARC is an acronym for Computer Aided Movement Analysis in a Rehabilitation Context and is an EEC (European Economic Community) program.

Cocontraction

The tendency of agonist and antagonist muscle to activate with identical timings.

Concentric Contraction

A muscle contraction that results in the shorting of the muscle length.

DST

This stands for Data Storage and Transfer and is an ASCII file format that was proposed by CAMARC to store biomechanics information in a well defined manner so that different motion analysis laboratories could exchange information.

Eccentric Contraction

A muscle contraction associated with the increase in length of a muscle.

EMG

EMG is an abbreviation for electromyography which is the study of the electrical manifestation of a contracting muscle.

Electrode

In electromyography an electrode is the electric conductor that conveys an electric current from a biological myoelectric source to an electronic amplifier.

GCD

Gait Cycle Data is an ASCII file format that was proposed by CAMARC to store gait cycle data. This is very similar to the DST format except that GCD files only contain information from a single gait cycle.

Hz

Hz is the abbreviation for "Hertz" which describes the frequency of electrical vibrations per second. One Hertz (written Hz) is equal to one oscillation per second. This is also commonly referred to as *cycles per second* in older literature. The name commemorates the German physicist Heinrich Hertz who, in 1883, detected electromagnetic waves.

Isometric Contraction

A muscle contraction during which the muscle length and associated joint angle do not change.

Isotonic Contraction

A muscle contraction that is maintained with a constant tension.

OSHA

In the United States, the Occupational Safety and Health Administration's mission is to assure worker safety and health by setting and enforcing standards, and encouraging improvement in workplace safety and health. Most countries have some regulatory body that performs a similar function.

Index

1,2, … filename 128
about EMG 131
About EMG 131
About EMG dialog box 131
add foot contact 69
add toe off 69
aliasing 121
Aliasing 121
Amplitude Distribution 119
Amplitude Normalization 41
Analog Signal Processing 153
Analysis 154
Analysis techniques 33
Analyze menu 109
Analyzing EMG 40
Application 36
Application Versions 6
arrange icons 127
Arrange Icons 127
Automation 55
basic graphing edition 7
BTS EMG Files 135
calibration
  MA-100 103
  MA-300 105
Calibration 103
cascade 127
Cascade 127
Caveats 35
Channel Options 80
channel properties 78
Channel Properties 78
Channel Properties dialog box 78
channels 64
Channels 64
Channels dialog box 65
Checking the EMG signal 32
clear events 68
Close 51
closing a file 51
Cocontraction 120
compression slider 111
correlation 120
Correlation dialog box 99
Crosstalk 30
Data Storage 153
Dataq CODAS Files 137
defaults 79
  channel options 80
  envelope 88, 89
  general 79
  graph 82
  IFA 91
  level detector 93
  raw 86
Defaults 79
dialog
  Normal EMG Data 61
dialog box
  About EMG 131
  Channel Properties 78
  Channels 65
  Correlation 99
  Edit Events 71
  Foot Switch Levels 70
  Graph Titles 64
  Process 124
  Registration 131
  Select Cycles 67
Discussion 133
Edit Events dialog box 71
electrodes 24
  active 26
  fine wire 28
  surface 24
Electrodes
  Artifact 19
EMG Amplification 152
EMG Analysis Application 3
EMG Analysis/Graphing 1
EMG Data Collection 39
EMG Electrodes 24, 151
EMG Power Spectrum 118
EMG Signal Averaging 42
Envelope Options 88, 89
evaluation 6
events
  add foot contact 69
  add toe off 69
  clear 68
  foot switch levels 70
  manual edit 70
Events 67, 110
exit 60
Exit 60
Export:C3D File 123
Export:GCD File 123

Features 2
file
closing 51
opening 51
saving 52
saving to a different name 52
File menu 50
filter envelope 114
Filtering the EMG signal 32
Fine Wire Electrodes 28
Fine Wire EMG 38
foot switch levels 70
Foot Switch Levels dialog box 70
Force 15
Frequency Analysis 45
Full Trial 111
Full Wave Rectified EMG 113
gait events
events in file 110
from foot switches 110
from force plate 111
General Options 79
Graph 73
Graph Options 82
graph titles 63
Graph Titles 63
Graph Titles dialog box 64
help menu 129
help topics 129
Help Topics 129
How is EMG measured? 17
IFA (Intensity Filtered Average) 116
IFA Options 91
Installation 141
Installation Overview 4
Integrate and Reset 118
Integrate over Time 117
Integrated EMG 44
intensity filtered average 116
Interpretation 36
Introduction 151
Joint motion 15
Level Detector Options 93
Linear Envelope 114
Listen to Channel 122
MA-100 calibration 103
MA-300 calibration 105
menu
File 50
help 129
View 72
window 127
MLS Home page 131
MLS Home Page 131
Most Recently Used file 59
Motion Analysis Corporation ANA Files 138
Moving Average 113
Muscle Fatigue 15
Noise Sources 31
normal EMG data 60
Normal EMG Data 60
Normal EMG Data dialog 61
normalization 107
Normalization 107
Obtaining the current version 9
Open 51
opening a file 51
Overview 141
Oxford Metrics ADC Files 134
Page Setup 59
playback channel 122
power spectrum 119
Preparation 31
print 58
Print 58
print preview 59
Print Preview 59
print setup 59
Print Setup 59
process 123
Process dialog box 124
raw data 111
Raw EMG 111
Raw Options 86
recently opened files 50
Recording Systems 17
Refresh 73
Register 130
registration 130
Registration 7
Registration dialog box 131
Relationship of EMG to physical parameters 14
Removing the Software 150
report 71
Report 71
RMS Analysis 115
Sampling Rate 18
Save 52
Save As 52
Save Channel to Wav 123
saving a file 52
saving a file to a different name 52
select cycles 67
Select Cycles 67
Select Cycles dialog 67
Signal Levels 22
sound, listen to 122
Sources used in this manual 157
spectrum 118
status bar 73
Surface Electrodes 24
Surface EMG 37

Templates ... 52
The Edit menu ... 60
The EMG Graphing Application ... 2
The File menu ... 50
The Fourier Transform ... 46
The Problem of Aliasing ... 20
The Scaling Menu ... 101
The User Interface ... 49
Threshold Detection ... 116
tile 127
Tile 127
Time domain analysis of the EMG signal ... 42
Time Normalization ... 41
toolbar ... 72
trial 111
Unscale Data / Scale Data ... 102
Updating to the Current Version ... 148
Using the Help system ... 129
VAD Files ... 139
Velocity ... 15
View menu ... 72
View Options ... 85
What is EMG? ... 11
Why is EMG measured and studied? ... 13
window envelope ... 113
window menu ... 127
Window menu ... 127
Zero Crossing ... 117